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TITLE: Method of track merging in an aircraft tracking system

Abstract Text (1):
A method of processing a plurality of tracks representative of one or more target aircraft in a vicinity of a surveillance aircraft, where each track is generated in response to target reply signals provided by the target aircraft in response to interrogation signals transmitted by the surveillance aircraft, includes eliminating a portion of the plurality of tracks which are duplicate tracks of the same target aircraft. The remaining tracks are maintained and updated in response to the target reply signals provided by the target aircraft. A threat level for each of the remaining tracks is determined and two or more of the remaining tracks which are possibly representative of a same target aircraft are merged resulting in a composite track. The composite track is output to a display device utilizing information from a particular remaining track of the composite track having the greatest threat level to the surveillance aircraft while continuing to maintain and update all the remaining tracks.

Brief Summary Text (2):
The present invention relates to a method of tracking target aircraft in an aircraft tracking system. More particularly, the present invention relates to a method of track merging in an aircraft tracking system to reduce clutter on a traffic display and to reduce aural alerts.

Brief Summary Text (4):
The increased demands put on aircraft flight crew as a result of more complex technology, ever increasing aircraft traffic, and increased demands for safety has brought about a requirement for monitoring aircraft traffic in the vicinity of a surveillance aircraft. Such monitoring includes the automatic identification of potential threats to a surveillance aircraft monitoring target aircraft in such vicinity. As a result, target aircraft have transponders which in response to appropriate interrogation signals return reply signals which may provide information with respect to the range, altitude and bearing of the target aircraft. Certain traffic control system transponders, such as the Mode S systems include unique aircraft identifiers so that each target aircraft is interrogated separately and each reply is stamped with the identity of the target aircraft. This significantly simplifies surveillance processing by the surveillance aircraft.

Brief Summary Text (5):
In systems such as an Air Traffic Control Radar Beacon System (ATCRBS), which do not include unique aircraft identification information in replies to interrogation signals, the determination of aircraft tracks representative of target aircraft from replies is more difficult. The information obtained by periodic interrogation of target aircraft during surveillance periods from the replies provided by the target aircraft are subjected to algorithms to provide a target aircraft track. Once the track is identified and initialized, then the track can be updated and monitored to determine if the target aircraft is a threat to the surveillance aircraft.

Brief Summary Text (6):
Track determination is complicated for several reasons, generally involving spurious target replies. For example, with reference to FIG. 1, a surveillance aircraft 10 can transmit an interrogation signal 16 to a target aircraft 12, whereupon a transponder

in the target aircraft 12 provides a first reply signal 18. The delay between the transmission of the interrogation signal and the reception of the reply signal provides range information concerning the distance of the surveillance aircraft from the target aircraft. However, the interrogation signal 16 can result in a second reply signal 19 that is reflected from the ground 14. The second reply signal 19, reflected once from the ground 14, is generally referred to as a single reflection multipath reply. Because the length of time for the travel of the second reply signal is longer than the first reply signal 18, the second reply signal 19 can be interpreted as being from a separate target aircraft at a greater range from the surveillance aircraft. A single reflection multipath reply also can be generated from the interrogation signal 17 being reflected off the ground 14 combined with the direct reply 18 to surveillance aircraft 10 from target aircraft 12. Since the path length is the same as the previous case, where the reply is reflected and the interrogation is direct, the range is the same. Similarly, the interrogation signal 17 can reflect off the ground 14, activate the transponder of the target aircraft 12 which provides a reply signal 20 that also reflects off the ground 14. In this instance, since both the interrogation signal 17 and the reply signal 20 are each reflected off the ground 14, this reply is referred to as a double reflection multipath reply. These double reflection multipath replies will be interpreted by the surveillance aircraft 10 as a target aircraft 12 at an even greater range than indicated by the direct or single reflection multipath replies.

Brief Summary Text (7):
In these situations, a single target aircraft is providing the surveillance aircraft 10 with a plurality of target responses during each interrogation. Thus, from a single surveillance period, consisting of multiple interrogations, multiple replies can be received from a single target aircraft. Such multiple replies may result in multiple tracks as shown in FIG. 2, where a direct reply track 101-103, a single reflection multipath track 104-106, and double reflection multipath 107-109 are indicated. Tracks can also be formed on mixtures of reply types, such as for a combination of single and double reflection replies. In addition, tracks can result from false replies due to electromagnetic interference or other effects such as ATCRBS transponder replies from insufficiently suppressing Mode S transponders.

Brief Summary Text (8):
As a result of the number of tracks which can be interpreted from the various replies from the target aircraft 12, a single target aircraft may have multiple tracks associated therewith. Such multiple tracks may be associated with a single ATCRBS transponder equipped target aircraft, however, will not occur with regard to a Mode S transponder equipped target aircraft as the Mode S equipped target aircraft has unique identification which prevent such multiple tracks from occurring. However, Mode S equipped target aircraft sometimes answer interrogations intended for ATCRBS equipped target aircraft and this may lead to ATCRBS replies in addition to the Mode S reply; thus forming duplicate tracks for a single Mode S equipped transponder target aircraft.

Brief Summary Text (9):
The multiple tracks for a single target aircraft may be referred to as split tracks. Such split tracks for a single target aircraft may be the result of multipath false replies. Split tracks may be displayed for an aircraft flight crew by a Traffic Alert and Collision Avoidance System (TCAS). Display symbols representative of target aircraft displayed as a result of one or more tracks of a split track results in excess clutter on the display and may also lead to excess aural messages to the flight crew. Such clutter is most prevalent at low altitudes and during turns when the flight crew workload is greatest. This excess clutter on the TCAS displays results in unnecessary and increased flight crew workload.

Brief Summary Text (10):
The Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment, manual document no. DO-185 by the Radio Technical Commission for Aeronautics (RTCA) which governs the operation of aircraft collision avoidance apparatuses, suggests an algorithm for merging split tracks based on multipath replies, insufficiently suppressed Mode S transponders, false replies, or other replies not accurately representative of target aircraft. This merging (in addition to enhanced merging functions) is performed in the TCAS surveillance functions. However, although some merging can be done in surveillance processes, the

criteria need to be conservative so that tracks representative of real target aircraft, as opposed to a track of a split track for a single target aircraft, are not eliminated. If a track of a real target aircraft is eliminated, such target aircraft tracks are no longer tracked or updated. A threat from such an aircraft cannot be immediately introduced to the flight crew by means of the TCAS display. It takes a few seconds to re-acquire a track once it is eliminated and it takes even longer for that track to stabilize. Thus, there is some time delay danger in not adequately monitoring real target aircraft if conservative criteria for track merging in a TCAS surveillance process or collision avoidance system (CAS) process are not utilized. Such loss of track information regarding a real target aircraft which presents a threat to the surveillance aircraft is unacceptable. Therefore, there is a need to provide further TCAS track merging capabilities to remove excess display clutter while maintaining a conservative approach to eliminating tracks which are potentially split tracks based on multipath replies, false replies, etc.

Brief Summary Text (12):
The present invention is directed to a method of processing a plurality of tracks representative of one or more target aircraft in a vicinity of a surveillance aircraft. Each track is generated in response to target reply signals provided by the target aircraft in response to interrogation signals transmitted by the surveillance aircraft. The method includes a step of eliminating a portion of the plurality of tracks which are duplicate tracks of a same target aircraft. The remaining tracks not eliminated are maintained and updated in response to the target reply signals provided by the target aircraft. A threat level for each of the remaining tracks is determined and two or more of the remaining tracks which are possibly representative of a same target aircraft are merged resulting in a composite track. The composite track is output to a display device utilizing threat level information from a particular remaining track of the composite track having the greatest threat level to the surveillance aircraft. The composite track is output to the display device while continuing to maintain and update all the remaining tracks.

Brief Summary Text (13):
In another embodiment of the invention, the merging step includes determining whether two of the remaining tracks have a similar bearing. It is also determined whether both of the two remaining tracks have unique addresses identifying them as separate target aircraft. If both remaining tracks do not have unique addresses and both have similar bearings, then it is determined whether both of the two remaining tracks are altitude reporting or non-altitude reporting tracks. If both tracks are altitude reporting tracks, range and altitude information of each of the tracks from the surveillance aircraft are compared to predetermined merge conditions. If both tracks are non-altitude reporting, then the range information is compared to the predetermined merge conditions. The two tracks are merged if the predetermined merge conditions are satisfied.

Brief Summary Text (15):
In another embodiment of the invention, an apparatus for processing a plurality of tracks representative of one or more target aircraft in a vicinity of a surveillance aircraft is described. Each track is generated in response to target reply signals provided by the target aircraft in response to interrogation signals transmitted by the surveillance aircraft. The apparatus includes surveillance means for initializing the plurality of tracks. The surveillance means includes means for eliminating a portion of the tracks which are duplicate tracks of particular target aircraft or false tracks non-representative of the target aircraft and also means for updating remaining tracks not eliminated in response to the target reply signals provided by the target aircraft. The apparatus further includes collision avoidance means for determining a threat level for each of the remaining tracks and merging means for merging two or more of the remaining tracks which are possibly representative of a same target aircraft resulting in a composite track. Output means outputs a single symbol for the composite track utilizing information concerning a particular remaining track of the composite track which has the greatest threat level to the surveillance aircraft while the surveillance means continues to maintain and update the remaining tracks.

Drawing Description Text (2):
FIG. 1 shows a diagram of possible signal paths of target aircraft replies in response

to surveillance aircraft interrogation signals.

Drawing Description Text (3):
FIG. 2 is a charted illustration of tracks for a single target aircraft

Detailed Description Text (2):
Referring to FIG. 1, there is shown a surveillance aircraft 10 engaged in an interrogation-reply process with a target aircraft 12. The surveillance aircraft 10, having a TCAS/transponder system 22, FIG. 3, interrogates all target aircraft, including target aircraft 12, in the vicinity of the surveillance aircraft 10 in order to determine potentially dangerous situations. The TCAS/transponder system 22 includes a transponder system 26, TCAS computer unit 24, TCAS displays 28, means for presenting aural messages 30, a top directional antenna 32, and a bottom directional or omni-directional antenna 34. TCAS/transponder system 22 installed on the surveillance aircraft 10 may utilize ATCRBS transponders and Mode S transponders installed in target aircraft to provide locations of such target aircraft in the immediate vicinity of the TCAS equipped surveillance aircraft 10. TCAS/transponder system 22 provides surveillance by transmitting interrogation signals to target aircraft for measuring the relative range, altitude and bearing from the replies provided by the target aircraft. The measured data and the rate of change of this reply data are utilized by the TCAS/transponder system 22 to provide a prediction of aircraft penetration into a predetermined TCAS protection volume for a subsequent flight time. When target aircraft penetration is predicted within this volume and time, an advisory is given to the flight crew to take corrective action by way of the display devices 28 and means for presenting aural messages 30.

Detailed Description Text (3):
TCAS computer unit 24 of surveillance aircraft 10 interfaces to a top directional antenna 32 and to a bottom o directional antenna 34. The bottom directional antenna 34 may instead be an omni-directional antenna. The TCAS computer unit 24 outputs interrogations and listens for replies from target aircraft provided in response to these interrogations through top and bottom directional antennas 32, 34. The replies from the target aircraft include multipath replies and false replies as indicated in the Background of the Invention section herein. Such multipath replies and false replies complicate the identification of a target aircraft track by the TCAS computer unit 24.

Detailed Description Text (4):
The TCAS computer unit 24 works in cooperation with the transponder system 26. The dual transponder system 26 includes a Mode S transponder 39, a Mode S or an ATCRBS transponder 35 and a control panel 41 used to control the transponders 35, 39 and the TCAS/transponder system 22. The transponder system 26, FIG. 3, is the transponder system of the surveillance aircraft 10 and is not the transponder system of target aircraft. The transponder system of the target aircraft is not shown, but may include a Mode S transponder, an ATCRBS transponder, or both. Mode S transponder 39 interfaces with omni-directional antenna 42 and omni-directional antenna 40 to provide and receive Mode S interrogations and replies. The Mode S transponder 39 directly interfaces with the TCAS computer unit 24. If transponder 35 is a Mode S transponder, the Mode S transponder 35 interfaces with the TCAS computer unit 24 and is associated with omni-directional antenna 36 and omni-directional antenna 38. However, if transponder 35 is an ATCRBS transponder, omni-directional antenna 36 is unnecessary and the local ATCRBS transponder 35 does not interface to TCAS computer unit 24. The local ATCRBS transponder 35 provides replies from surveillance aircraft 10 to other surveillance aircraft which have transmitted interrogation signals to the surveillance aircraft 10 to allow other surveillance aircraft to determine whether surveillance aircraft 10 is a potential threat to the other surveillance aircraft.

Detailed Description Text (5):
The TCAS computer unit 24 of the surveillance aircraft 10 processes replies of target aircraft which may be equipped with two types of transponders, ATCRBS transponders and Mode S transponders. In the case of ATCRBS transponder equipped target aircraft, there is no unique aircraft identifier so the process of identifying and tracking target aircraft is complicated. Because such complication exists, it is necessary for surveillance process 48, FIG. 4, to determine which replies belong to which target aircraft and to reject multipath and false replies a described in the Background of

the Invention section herein which may be representative of a single target aircraft. Tracks initialized from such multipath replies or false replies representative of a single target aircraft shall be referred to as split tracks as discussed previously.

Detailed Description Text (6):
In the case of Mode S transponder equipped target aircraft, there is a unique aircraft identifier, so each target aircraft is interrogated separately and each reply is stamped with the identity of the responding target aircraft. Since Mode S equipped target aircraft have unique aircraft identifiers, multiple Mode S tracks for a single target aircraft do not occur. However, multiple ATCRBS tracks as well as a single Mode S track may occur for a single Mode S equipped target aircraft. Split tracks due to the processing of multipath replies and other effects often occur for a single ATCRBS equipped target aircraft. Such split tracks are the tracks responsible for clutter on the TCAS displays in the flight crew work areas as can be seen in FIG. 7A.

Detailed Description Text (7):
The TCAS computer unit 24 of the surveillance aircraft 10, includes programs for executing primary TCAS processes 46, FIG. 4, utilizing information from the interrogation/reply method between the surveillance aircraft 10 and target aircraft. In particular, the primary TCAS processes 46 include surveillance process 48 which identifies target aircraft and provides collision avoidance system (CAS) process 50 with target aircraft data. The CAS process 50 determines the threat level of the target aircraft from the data supplied from the surveillance process 48 and furnishes such threat level information to display preprocessing 52 such that the threat level information can then be furnished to the flight crew through display devices 28 and means for presenting aural messages 30. Such aural presentation means 30 may be any appropriate annunciation equipment.

Detailed Description Text (8):
FIG. 4 shows in block diagram form an overview of the primary TCAS processes 46. FIG. 4 has been simplified and does not show the exact sequence of processing events. For example, the TCAS/transponder system 22 interrogates an ATCRBS equipped target aircraft using an interrogation sequence consisting of approximately 100 further steps. After each step, the TCAS/transponder system 22 listens for replies. At the end of the ATCRBS interrogations of the ATCRBS equipped target aircraft, the TCAS system 22 processes the ATCRBS replies from the target aircraft and tracks the target aircraft resulting therefrom. This ATCRBS processing takes place concurrently with the processing of replies from Mode S equipped target aircraft. Surveillance process 48 interrogates each qualified Mode S equipped target aircraft and after each Mode S interrogation, TCAS/transponder system 22 listens for replies, processes the replies and updates the tracks representative of such Mode S equipped target aircraft. The timing of such concurrent processing is not shown in FIG. 4.

Detailed Description Text (9):
Surveillance process 48 of the primary TCAS processes 46 includes the execution of various program processes. Surveillance process 48 interrogates a target aircraft 12 (Block 54) by performing a predetermined interrogation sequence transmitting interrogation signals to target aircraft. The surveillance process 48 then listens for replies (Block 56) from target aircraft. The replies are then processed (Block 58) to prevent duplicate replies and false replies. Such false replies may include reply signals which are a result of electromagnetic interference or other effects. After elimination of such replies, surveillance process 48 then selects the replies for tracks that have been previously identified for particular target aircraft (Block 60). The previously identified particular tracks can then be updated with the new reply information. If a reply for a previously identified track cannot be located, this previously identified track is coasted (Block 60). Such coasted tracks if not updated for a sufficient period of time, for example six surveillance periods, are dropped and no longer followed or updated.

Detailed Description Text (10):
When all of the previously identified tracks for particular target aircraft have been updated, the surveillance process 48 proceeds in initiating new tracks having particular range, altitude and bearing, if available (Block 62). In the case of the ATCRBS transponder equipped target aircraft, the replies from such aircraft which are remaining after reply processing (Block 58) and track updating (Block 60) are used to

initiate the new tracks.

Detailed Description Text (11):
Following the initialization of new tracks, false tracks or multipath tracks are identified (Block 64). For example, MOPS suggests an algorithm for merging split tracks, based on multipath tracks or false tracks, in surveillance process 48. Such track merging algorithms in the surveillance process 48 must be of a conservative nature so that real target aircraft are not eliminated. For example, the two tracks which are proposed to be merged in the surveillance process 48 may actually be representative of two real target aircraft. When a track representing one of these two real target aircraft is dropped, all the history on the track is lost and, as indicated in the Background of the Invention section herein, there is some danger in not adequately monitoring the real target aircraft and presenting the flight crew with misinformation or inadequate information

Detailed Description Text (12):
Following the merging of split tracks, based on multipath tracks or false tracks, on a conservative basis, the coasting tracks which have not been updated for some period of time as discussed above are dropped (Block 66) and the tracks identified which ar representative of target aircraft and which contain substantially accurate information are sent to CAS process 50. Further information with regard to surveillance process 48 is described in U.S. Pat. No. 5,107,268 to Sturm, et al. issued 21 Apr. 1992 hereby entirely incorporated herein by reference thereto. The CAS process 50 receives the data concerning the tracks from surveillance process 48. The CAS process 50 tracks its own altitude, i.e. the altitude of the surveillance aircraft 10, and selects CAS parameters such as threat protection volumes based on selected sensitivity levels, altitude bands, etc. Such parameters are also updated (Block 70). The track data received from surveillance process 48 is processed along with the tracking of data itself by CAS process 50 to track the target aircraft represented by the track data with respect to the surveillance aircraft (Block 72).

Detailed Description Text (13):
Target aircraft which qualify as threats to surveillance aircraft 10 are identified (Block 74). If there are any qualifying threats identified, then CAS process 50 determines a resolution advisory for the threats. If there are multiple threats, CAS process 50 considers all of the threats, or potential dangerous target aircraft, and determines a single composite resolution advisory (Block 78). It is necessary for coordination to take place with each TCAS identified target aircraft which is generating a resolution advisory to assure that complementary advisories are utilized (Block 78). Additional logic resolves conflicts between the resolution advisories. Detected aircraft which pose threats to surveillance aircraft 10 are identified by various advisory levels other than resolution advisories. Such advisory levels include traffic advisories, proximate traffic advisories and other traffic advisories (Block 80). The advisory levels for the target aircraft identified and which are potential threats to the surveillance aircraft 10 are sorted by advisory level (Block 82) and ~~sent to display~~ preprocessing 52 (Block 84). Display preprocessing 52 processes the list of target aircraft represented by their tracks to merge split tracks (Block 86). Merge processes (Block 86) will be explained further below with respect to the present invention. A display output, utilizing such apparatus as a graphics processor (Block 88) is generated and the images are displayed on display devices 28.

Detailed Description Text (14):
Display devices 28 may include traffic advisory (TA) displays or resolution advisory (RA) displays. Such TA displays and RA displays may or may not be combined. It is also possible to put a TA display on another instrument such as a weather radar or to modify a Vertical Speed Indicator with eyebrow lights to indicate resolution advisories. One example of a combined TA and RA display 150 is shown in FIG. 7A and 7B. With reference to FIG. 7A, the combined TA and RA display shows the surveillance aircraft symbol 185, a range ring 182, a resolution advisory ring 180, and traffic symbols for target aircraft. Target aircraft identified as resolution advisory target aircraft are displayed as solid squares, traffic advisory target aircraft are shown as solid circles, proximate traffic advisory target aircraft are shown as solid diamonds and other target aircraft advisories are shown as outlined diamonds. The relative altitude (in 100's of feet) for altitude reporting target aircraft is included next to the target aircraft symbol and the altitude trend is given by an upward, downward or

no arrow. The RA display portion of the combined display combines a vertical speed indicator with shaded rings 180 which indicate the vertical speeds which the pilot should not fly (darker shade) 193 or should fly (lighter shade) 191. The darker and lighter shaded rings are only present when a resolution advisory is in effect.

Detailed Description Text (15):
The display devices 28 present visual display of target aircraft to the flight crew along with presentation of aural messages 30. The aural messages or annunciations are associated only with symbols of target aircraft sent to the display devices 28. The aural annunciations also occur when the threat level status of the target aircraft are changed to a higher or lower classification. Some possible threat level states are increased resolution advisory, resolution advisory, weakened resolution advisory, preventative advisory, clear of conflict advisory, traffic advisory, proximate advisory, and other advisories.

Detailed Description Text (16):
As indicated previously above, some merging of split tracks for a single target aircraft is performed in surveillance process 48, but the criteria must be conservative so that tracks of real target aircraft are not eliminated and are continued to be tracked if such split tracks actually turn out to be two separate target aircraft rather than a split track for one single aircraft. In order to reduce the clutter on a TCAS traffic display due to split tracks, merge process (Block 86) identifies such split tracks and eliminates all but one of the tracks on what is considered to be a single target aircraft prior to sending the display output representative of target aircraft to the display devices 28. This method eliminates clutter on the traffic display due to the split tracks and eliminates excess aural annunciations made when display output representative of the split tracks are sent to the display device 28. At the same time, the information concerning all relevant threats and advisories for the tracks, whether a part of a split track identified by the merge process (Block 86) or not, is retained. This relevant threat and advisory information is retained by surveillance process 48 and CAS process 50 which continue to process all of the target aircraft tracks regardless of the merge process. Thus, if the tracks separate into two or more distinct target aircraft the information concerning such tracks is immediately available for output to display devices 28 as representing separate established and stabilized tracks and the aural annunciations 30 for each separate track can be provided to the flight crew immediately.

Detailed Description Text (17):
The merge process (Block 86) of display preprocessing 52 shall be described in further detail with reference to FIGS. 5-7B. Merge process (Block 86) processes two or more tracks representative of possible target aircraft such that when this group of tracks meet certain target aircraft type, range, altitude and altitude rate requirements, the tracks are combined into a single composite aircraft for purposes of displaying a symbol for the target aircraft on display device 28 and issuing a single aural message 30 for them if applicable. As a result of merging the group of tracks into a single composite target aircraft for purposes of display and aural messages, excess symbols on such display devices 28 and aural messages for the output are eliminated. In the case of the RA display portion of combined display 150, FIG. 7A, there will be no difference in the RA display portion before or after the merge process (Block 86) is implemented since the resolution advisory sent to the RA display portion of the combined display always is a composite of the resolution advisories from all the tracks of all target aircraft generated by the algorithms of CAS process 50. However, the TA display portion of the combined display will be sent a symbol of a composite target aircraft and consist of the highest threat level of the group of tracks merged and the range, altitude, and bearing of the track representative of the closest target aircraft in the group rather than showing symbols for each track of the group. Although the aural annunciations for display of resolution advisories are unaffected as a composite of the resolution lo advisories is displayed on the RA portion of the display, the other aural alerts associated with the display of symbols for other target aircraft are reduced as only one aural message will be annunciated for each group of tracks merged and displayed as a composite track.

Detailed Description Text (18):
Because a group of merged tracks may actually be representative of more than one target aircraft, the surveillance process 48 and CAS process 50 update the tracks of

each aircraft of the group of merged tracks. At a later time, the tracks of the merged group may fail to meet the requirements to be merged. In other words, the processing of the tracks of target aircraft which were merged by merge process (Block 86) in the past, may fail the split track merging criteria or requirements at a later date. The RA display portion of combined display 150 will remain unchanged whether the merged tracks unmerge or continue to be merged since CAS process 50 still generates a composite resolution advisory to be displayed. However, when the tracks of the target aircraft unmerge or no longer meet the split track merging requirements, they are re-displayed immediately on the TA display portion of the combined display as such tracks are still being updated by surveillance process 48 and CAS process 50. Aural annunciations for the new target aircraft which were considered a portion of the prior merged target aircraft will occur when the split tracks previously merged are unmerged only if the target aircraft's threat level changes to a higher or a lower state.

Detailed Description Text (19):
An example of the results of merge process (Block 86) of display preprocessing 52 ar shown in FIG. 7A and FIG. 7B. FIG. 7A, prior to implementation of merge process (Block 86), represents a combined RA and TA display 150 having a resolution advisory ring 180 which is only active when a resolution advisory is in effect, the surveillance aircraft symbol 185, the range ring 182, symbols representative of a resolution advisory 164, 162, traffic advisory symbol 154, proximate traffic advisory symbol 152, and other traffic symbols 156, 158, 160. After implementation of merge process 86, FIG. 7B, the clutter of the RA and TA display 150 is substantially reduced. The symbols 162 and 164 are merged into a single symbol 170, proximate traffic symbol 152 and traffic advisory symbol 154 are merged into a single traffic advisory symbol 172, and the three other traffic symbols 156, 158, 160 are merged into one other traffic symbol 174. As can be seen from a comparison of FIG. 7A and FIG. 7B, the resolution advisory ring 180 is unchanged as a resolution advisory is still in affect and the RA display portion of the combined RA and TA display 150 is unchanged.

Detailed Description Text (20):
The merge process (Block 86) shall specifically be described with reference to FIGS. 5, 6A and 6B. Two or more tracks representing target aircraft shall be considered split tracks from a single target aircraft and will be merged when target aircraft type requirements, range requirements, altitude requirements and altitude rate requirements are satisfied as described below. If such requirements are not satisfied, then the two or more tracks are not merged and are represented on display device 28 as separate symbols representing more than one target aircraft. The merge process 86 is shown in the flow diagram of FIGS. 6A and 6B. The merge requirements or conditions shall be explained further below with reference to the flow diagram.

Detailed Description Text (21):
As indicated by the Blocks of the flow diagram, FIGS. 6A and 6B, two tracks representative of target aircraft are compared to each other and it is determined whether the tracks being compared are a split track and should be merged (Block 211) or whether the two tracks do not represent a split track, and should not be merged (Block 209, 210). If a merge does occur, then the track representative of a target aircraft closest to the surveillance aircraft position is selected (Block 212) and this track representative of the closest target aircraft is then compared with any other ~~tracks which have not~~ been tested by the merge process (Block 215). This process is continued until all of the tracks of target aircraft have been tested and the process is done. (Block 216). As such, multiple tracks can be merged into a single track for display of a single symbol for a target aircraft on display devices 28.

Detailed Description Text (22):
Target Aircraft Type Requirements

Detailed Description Text (23):
Both tracks being compared must have bearing information (Block 200). If they do not both have bearing information, then the tracks are not merged (Block 210). If they both have bearing information, then it is determined whether both tracks are representative of Mode S transponder equipped target aircraft. Since ATCRBS transponder equipped target aircraft do not have unique identifiers, multiple tracks for a single ATCRBS equipped target aircraft often occur. On the other hand, Mode S transponder equipped target aircraft have unique identifiers associated therewith,

therefore, multiple Mode S tracks on a single target aircraft do not occur. Although, a Mode S transponder of a target aircraft is not supposed to reply to a ATCRBS interrogation, the Mode S transponder might reply under some conditions, for example, if a suppression pulse of the interrogation from the surveillance aircraft is not detected by the Mode S transponder equipped target aircraft. For this reason, a duplicate Mode S formulated track and ATCRBS formulated track on a single intruder may exist and must by considered by the merge process 86. In other words, a Mode S formulated track and another Mode S formulated track are not merged. On the other hand, a Mode S formulated track and an ATCRBS track are given further consideration by the merge process 86. As such, if both tracks are not from Mode S equipped target aircraft (Block 201), then the altitude requirements are considered. Otherwise, the tracks aren't merged (Block 210).

Detailed Description Text (25):
The altitude requirements can be split into two steps. The first step is applicable to tracks which represent target aircraft which are both altitude reporting (Block 202) and the second with respect to tracks which represent target aircraft which are non-altitude reporting (Block 204). If one track is altitude reporting and the other track is non-altitude reporting, then the two tracks are not merged (Block 209).

Detailed Description Text (26):
When both tracks are of target aircraft having altitude reporting, then the altitude of the tracks and the altitude rate of the tracks are considered (Block 203, 205). When both the tracks are altitude reporting, it is determined whether the altitude rate difference between the tracks is less than 600 feet per minute (Block 203). If the altitude rate difference requirement is satisfied for altitude reporting tracks, then the relative altitude difference between the tracks is considered (Block 205). If the relative altitude difference between the tracks is less than 75 feet, then the merge process 86 further considers these tracks with regard to range requirements (Block 206). However, if the altitude rate difference between the tracks is greater than or equal to 600 feet per minute or if the relative altitude difference between the tracks is greater than or equal to 75 feet (Block 203, 205), then the two tracks are not merged (Block 210) .

Detailed Description Text (29):
Range requirements are determined by considering multi-path and parallel approaches/departures for landing and takeoff. Parallel approaches/departures occur near terminal control areas and lead to close separation between target aircraft. It is desirable for these target aircraft to be tracked separately. Therefore, when the surveillance aircraft approaches the terminal area where landing and takeoff is in the near vicinity, different range requirements are required than for when the surveillance aircraft is far from the landing and takeoff of target aircraft.

Detailed Description Text (30):
If the altitude requirements are met, the two tracks are merged depending on the following requirements. First, if the range (R) of the track representative of the greatest threat to the surveillance aircraft is less than or equal to three nautical miles and the altitude of the surveillance aircraft above ground level is less than or equal to two thousand feet (Block 206), then if the range separation between the two tracks being compared is less than or equal to six hundred feet (Block 207), a split track exists and the two tracks are merged (Block 211). Such conditions are for when the surveillance aircraft is within the vicinity of a terminal.

Detailed Description Text (31):
If the range (R) of the track representative of the greatest threat to the surveillance aircraft is greater than three nautical miles, or if the altitude of the surveillance aircraft above ground level is greater than two thousand feet (Block 206), then the tracks are considered a split track if the range separation between the tracks of the target aircraft is less than or equal to one nautical mile or R/8 whichever is less (Block 208). These conditions are for when the surveillance aircraft is not close to the vicinity of a terminal. If neither of these range conditions or requirements are met, then a split track does not exist and the tracks are not merged and will be shown separately on display device 28.

Detailed Description Text (33):

As shown in FIG. 5, it can be seen that R is equal to the distance from surveillance aircraft 10 to target aircraft 12 because target aircraft 12 is the greatest threat to surveillance aircraft 10. Therefore, the spherical volume covers the volume about aircraft 12. If target aircraft 13 falls within the volume then it would be merged with tracks representative of target aircraft 12 if the other requirements are satisfied.

Detailed Description Text (34):
When two or more tracks meet the split track merge requirements and are merged (Block 211), the track of the closest target aircraft to the surveillance aircraft is selected for further processing with regard to other track as discussed above (Block 212). The threat level assigned to the closest target aircraft by the merge process 86 will be the highest threat of all the identified split tracks which are merged as the closest track of each pair of split tracks is selected (Block 213). In accordance with Block 214, a single aural message is established for the group of tracks which are merged and unnecessary aural messages for each track are not allowed.

Detailed Description Text (35):
Output process (Block 88) of display preprocessing 52 then outputs the top number of advisory level target aircraft to the display devices 28 after the merge process 86 is completed. The aural messages are also output to annunciation means 30. The aural annunciations will be associated only with the intruders sent to the display devices 28. This will eliminate extraneous aural annunciations corresponding to track information not sent to the external display devices 28. When the merged tracks no longer meet the split track merge criteria, aural annunciations will occur when the intruder's threat level changes to a higher or lower classification.

Detailed Description Text (36):
The merge process 86 reduces the clutter resulting from false tracks being displayed to the flight crew on a TA display, while retaining all relative threat and position information. The merged tracks representing a composite target aircraft sent to the external display devices shall have the highest threat level of any of the group of tracks which were merged. Also, the range, altitude and bearing for the composite track will be that of the target aircraft that is closest to the surveillance aircraft. As indicated previously, the split track merge reduction has no affect on the RA display or its annunciations. The RA display shows a composite of all the individual resolution advisories generated by CAS process 50.

Detailed Description Text (37):
Unlike the inclusion of severe track merging algorithms in surveillance process 48 or in CAS process 50, there is no corresponding danger in merging target aircraft tracks in the display software since both surveillance and CAS processes maintain all the tracks and the moment the merged tracks diverge representing two separate real target aircraft, they can be re-displayed as stable tracks with an adequate history. In addition, threat levels are maintained separately on each of the merged tracks and the composite symbol on the TA display portion shows the highest threat level of all the merged tracks.

Detailed Description Text (38):
One example in which merging tracks in the display software rather than in surveillance process 48 is beneficial can be seen in the case of tracks which cross each other in the range whose altitudes and bearings are similar. If the track merging were done in surveillance process 48, one of the tracks would be dropped. This target aircraft would then not be tracked until it diverted adequately from the other target aircraft. It would take a few seconds for the surveillance process 48 to re-acquire the target aircraft which is dropped and even longer for the track representative of the target aircraft to stabilize. Thus, surveillance process 48 would lose track of one of the target aircraft for a few seconds. With the track merging performed in display preprocessing 52, the display symbols are merged into one symbol and the moment the tracks diverge adequately representing both real target aircraft, the two symbols would be re-displayed. Both target aircraft would continue to be tracked by surveillance process 48 and CAS process 50 during the time when their symbols were merged. The full history of both tracks representative of the two real separate target aircraft is maintained and a resolution advisory is generated on either target aircraft throughout the entire period when the two tracks are crossing.

Other Reference Publication (1):
U.S. Patent Application Ser. No. 07/968,100 "A Method of Aircraft Tracking System".

Other Reference Publication (3):
U.S. Patent Application Ser. No. 07/976,150 "A Method of Improved Initial Transmission of Acquisition and Tracking Interrogations in an Aircraft Tracking System".

CLAIMS:

1. A method of processing a plurality of tracks representative of one or more target aircraft in a vicinity of a surveillance aircraft, each track generated in response to target reply signals provided by the target aircraft in response to interrogation signals transmitted by the surveillance aircraft, said method comprising the steps of:

eliminating a portion of the plurality of tracks which are duplicate tracks of a same target aircraft;

maintaining and updating the remaining tracks in response to the target reply signals provided by the target aircraft;

determining a threat level for each of said remaining tracks;

merging two or more of said remaining tracks which are possibly representative of a same target aircraft resulting in a composite track;

and

outputting said composite track to a display device utilizing information from a particular remaining track of the composite track having the greatest threat level to the surveillance aircraft while continuing to maintain and update all said remaining tracks.

2. A method according to claim 1, wherein said merging step comprises the steps of:

determining whether two of the remaining tracks have a similar bearing;

determining whether both of said two of the remaining tracks having unique addresses identifying them as separate target aircraft;

if both remaining tracks do not have unique addresses and both have similar bearings, determining whether both of said two remaining tracks are altitude reporting or non-altitude reporting tracks;

if both tracks are altitude reporting tracks, comparing altitude information of each of the tracks and also comparing range information of each of the tracks from the surveillance aircraft to predetermined merge conditions; and

if both tracks are non-altitude reporting, only comparing the range information to the predetermined merge conditions; and

merging said two tracks if said predetermined merge conditions are satisfied.

3. A method according to claim 2 wherein said merging step further includes the steps of:

selecting one of said two of the remaining tracks having the highest threat level to the surveillance aircraft; and

testing the selected track with regard to other remaining tracks in accordance with the process steps of claim 2 to determine if the other remaining tracks should be merged with the already merged tracks.

5. A method according to claim 2, wherein the range comparing step comprises the step

of utilizing predetermined merge conditions of more strict levels when said vicinity is near aircraft landing and/or takeoff.

7. A method according to claim 1, wherein said merging step includes the step of:

determining that two or more remaining tracks which were merged represent two or more separate aircraft; and

immediately outputting tracks to said display device representative of such two or more separate target aircraft.

8. A method according to claim 7, further comprising the step of transmitting aural annunciations for the tracks representing the two or more separate aircraft when such two or more separate aircraft are identified.

10. An apparatus for processing a plurality of tracks representative of one or more target aircraft in a vicinity of a surveillance aircraft, each track generated in response to target reply signals provided by the target aircraft in response to interrogation signals transmitted by the surveillance aircraft, a portion of the plurality of tracks which are duplicate tracks of particular target aircraft or false tracks non-representative of target aircraft are eliminated and a remainder of the tracks not eliminated are updated in response to the target reply signals provided by the target aircraft, a threat level for each of the remainder tracks is determined, an improvement of the apparatus comprising: means for merging two or more of the remainder tracks which are possibly representative of a same target aircraft resulting in a composite track and for outputting a single symbol for the composite track utilizing the information concerning a particular remainder track of the composite track which has the greatest threat level to the surveillance aircraft while continuing to maintain and update the remainder tracks.

12. An apparatus according to claim 10, wherein said means is further defined as being for determining whether the two or more of the remainder tracks merged into a composite track are actually two separate target aircraft by utilizing the maintained and updated remainder tracks.

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L8: Entry 19 of 31 File: USPT Oct 20, 1992

DOCUMENT-IDENTIFIER: US 5157615 A
TITLE: Aircraft traffic alert and collision avoidance device

Brief Summary Text (45):
Traffic being tracked as reflected in the updated records is then prioritized by assigning a priority to each record based on altitude offset and range. The TCAD display then displays selected parameters from the highest priority threat. If there is additional traffic being tracked, the display identifies the existence of such other traffic. The pilot can, by manipulating the keyboard, either call for the display of other parameters from the highest priority threat or the display of parameters from second or third level threats.

Brief Summary Text (47):
TCAD, in addition to proximity warning and collision avoidance information, also provides for certain ancillary functions. Maintaining proper altitude is so important that it is now a criterion which is actively being monitored by air traffic control centers. As an assist to the pilot, TCAD has an altitude deviation alert. The altitude deviation alert can be selected or engaged when the host reaches a desired altitude. TCAD receives reports from the host blind encoding altimeter as to host altitude. Current host altitude is repeatedly compared to the altitude at which the altitude deviation alert was engaged. If the difference between these altitudes reaches a first predetermined criterion, an altitude deviation audio alert is enabled, signaling to the pilot the altitude deviation that has been noted. The pilot can either return to the desired altitude, disable the altitude alert, or if the deviation and altitude reaches a second predetermined criterion, then the altitude deviation alert is automatically disengaged.

Detailed Description Text (3):
FIG. 4 also shows the host 100 equipped in accordance with the present invention (TCAD). The host 100 includes, in addition to the equipment carried on the typical craft 50, a TCAD receiver processor 102, a TCAD keyboard/display 103 and an antenna 101. The TCAD receiver processor 102 is designed to receive 1090 MHz replies and to decode valid replies. One function of the TCAD keyboard/display 103 is to allow the user to program the THD and ALT parameters. Accordingly, the TCAD keyboard/display 103 provides an input to the TCAD receiver processor 102 corresponding to the programmed parameters. The TCAD receiver processor 102 also receives the same arometric pressure information which the blind altimeter 53 provides to the transponder 52; the path for this information is shown as the path 105 in FIG. 4. Another function of the TCAD receiver processor 102 is to suppress the transponder 52 at appropriate times via a signal coupled from the receiver processor 102 to the transponder 52 over the path 104.

Detailed Description Text (4):
The TCAD receiver processor 102, based on the parameters received from the keyboard display 103, the host altitude (received from the blind altimeter 53) and the replies from traffic maintains a running record of selected traffic craft. As has been explained the TCAD receiver processor 102 accepts input from the keyboard 103K to select among one of three pre-programmed shield volumes (TRML for a terminal flight regime, STD for standard or transition flight regimes and ENRT for enroute flight regimes). Each shield volume defines a vertical cylinder which has a thickness and radius. Replies from any aircraft found within the selected shield volume result in actuation of an audible warning to the host aircraft. Furthermore, aircraft outside

the shield volume, but reasonably close to the shield boundaries are tracked and parameters of such craft will be displayed. TCAD will show vertical direction, vertical separation, vertical trend (toward or away from host) and calibrated range from host for that craft with the highest threat potential. Viewing the changes (if any) in the range parameter provides the pilot with range trend as well. TCAD will also indicate the existence of one or two other craft also being tracked. Corresponding parameters of such other craft may also be displayed on request. In addition, the identity (Mode A reply) and MSL altitude of any of the primary threat aircraft can also be displayed on request. Traffic craft are prioritized in terms of threat probability. An audible warning is provided to the user in the event a traffic craft penetrates the shield. In the event of such a shield penetration, the user is provided information as to the traffic altitude, range, trend and identity, allowing the user to decide whether or not maintaining host altitude is preferred, or in the alternative, whether a change to host altitude is indicated. The TCAD receiver processor 102 will also accept information to determine the parameters (vertical separation and range) for any or all of the shield volumes (TRML, STD, ENRT).

Detailed Description Text (76):
FIG. 6 is a block diagram of the processor portion of the receiver processor 102. The microwave receiver REC shown in FIG. 6 is the receiver whose block diagram is shown in FIG. 5. The output of the microwave receiver REC is input to the A to D converter 110. The output of the A/D converter 110 is coupled both to the system controller 111 and to the comparator 114. The pulse width discriminator 112, driven from the comparator 114, generates the receiver interrupt, as described. The system controller 111 accepts the data from the A/D converter 110 and, writes that data to the HIGH SPEED DATA RAM 113a. The CPU allows the system controller 111 to write the input data only during a suppression/listen duration. At the end of the suppression/listen duration the access, by the system controller 111 to the HIGH SPEED DATA RAM 113a is terminated until the beginning of the next suppression/listen duration. The data that has been written is then moved to a buffer only if a receiver interrupt occurs during the suppression/listen duration. In the absence of a receiver interrupt the data which has been written is ignored, and overwritten during the next suppression/listen duration. The bus 130 also couples a buffer interface 118 which is driven by the information on path 105 from the blind encoding altimeter 53. The keyboard/display 103 includes a 7-button keyboard 103K. An output from the 7-button keyboard 103K is provided to a buffer interface and debounce element 119. The output of the buffer interface and debounce element 119 is coupled to the system bus 130. The system bus drives a system controller 123 which in turn drives a 16-character display 103D which is a portion of the keyboard/display 103. The bus 130 also couples the CPU 120 via a system controller 121 to a sound generator 124 whose output drives a speaker 125. The CPU is also coupled, via bus 130, to the timer 106. At various times the timer 106 is set and enabled to time either a suppression/listen duration W, the interval X or the Z portion of an interval. When the timer detects the end of the period being timed, it sets a flag (visible to the CPU 120) and also generates a timer interrupt. Finally, the CPU 120 also drives, via the bus 130, a system controller 122 whose output is provided over the path 104 for the purpose of suppressing the transponder 52. Photocell 127 senses ambient light levels. The output of the photocell 127 is coupled via the A/D converter 126 and system controller 123 to the CpU 120. This information is used to adjust the intensity of the display 103D. In an embodiment which has been constructed, CPU 120 is a Motorola 68000 chip.

Detailed Description Text (127):
In altitude, the algorithm of FIG. 10 performs pairing of Mode A and corresponding Mode C replies. Mode "A" replies that are identical in code are considered from the same aircraft and treated as such. Replies are compared on the basis of T (time) and cNM (range), and if they are of matching codes, and have arrived within for example 0.1 seconds of each other, and if they are within for example 0.1 cNM, they are tracked as a single aircraft, with the algorithm updating existing records. Further, if there is a Mode "C" reply that compares in T (0.1 seconds) and cNM (0.1 cNM), the Mode "A"and the Mode "C" are paired, so that the Mode A identification (squawk) from traffic is available for display to the pilot. (It should be understood that the time and distance criteria may be varied without departing from the invention.)

L18: Entry 5 of 7 File: USPT May 3, 1977

DOCUMENT-IDENTIFIER: US 4021009 A
TITLE: Vertical path control for aircraft area navigation system

Abstract Text (1):
In the vertical path control of an area navigation system when the aircraft ascends or descends to a waypoint with an "at-or-above" or "at-or-below" altitude requirement, vertical steering is effected at a constant airspeed with regard to a reference airspeed. An alert device is included to provide a warning to the pilot when the aircraft flight path angle is less than the straight line flight path angle to the waypoint for "at-or-above" waypoints or when the flight path angle of the aircraft is greater than the straight line flight path angle to the waypoint for waypoints with an "at-or-below" altitude requirement. Altitude error is displayed on a vertical deviation indicator of an aircraft flight instrument in accordance with the difference between the actual aircraft altitude and the altitude of the next waypoint having a firm altitude requirement. When the aircraft ascends or descends to a waypoint through the pressure-barometric altitude transition, flight path angles are computed and utilized as the vertical steering reference to avoid a steering discontinuity at the transition altitude. When the aircraft is on a descent path to a waypoint and an airspeed reduction is required, vertical angles are computed and utilized for generating the vertical steering signal whereby a speed reduction transition zone is included in the flight path to effect the speed reduction and make good the desired waypoint altitude.

Brief Summary Text (3):
The invention relates to aircraft area navigation systems (RNAV) particularly with regard to systems that provide vertical navigation control.

Brief Summary Text (5):
Prior Art RNAV systems provide vertical navigation on straight line paths from one altitude to another. Such systems have been restricted to fly vertical paths that are defined by a final altitude and a constant vertical flight path angle to that altitude. The termination altitudes are those assigned to waypoints, i.e. fixes utilized by the RNAV system for lateral navigation. One of the simplest conventional vertical paths is point-to-point navigation from one waypoint to another. The prior art RNAV systems connect the first waypoint with its associated altitude to the second waypoint with the altitude associated therewith utilizing a straight line, the system computing the flight path angle defining that line. Vertical navigation control is then based on deviations of the aircraft above or below this line.

Brief Summary Text (6):
Although such straight line navigation provides acceptable performance for many flight conditions, optimum performance is not obtained during particular specialized procedures. For example, it is often required during standard departure and arrival procedures that the aircraft cross defined waypoints "at-or-above" or "at-or-below" specified altitudes. On an "at-or-above" designation it is desirable that the aircraft climb to cruise altitude as quickly as possible to conserve fuel. The climb gradient varies with such factors as aircraft gross weight and atmospheric conditions. Under manual control such climbs are often flown at fixed airspeed or Mach number. However, if the procedure is to be predefined for the automatic navigation of a conventional RNAV system wherein the aircraft is restricted to fixed straight line flight paths, then the worst case angle for the heaviest aircraft must be selected thus diminishing performance efficiency for most aircraft or the pilot must manually select each

waypoint altitude based on his estimate of aircraft performance which is an undesired pilotage task. Alternatively, with conventional RNAV systems that require the aircraft to fly a fixed vertical flight path angle when climbing or descending, depending on atmospheric conditions and weight, the aircraft may not be able to maintain the constant flight path angle requiring the pilot to disconnect the system and fly the aircraft manually.

Brief Summary Text (7):
Another problem in the vertical path control of conventional RNAV systems occurs when the altimeter reference is changed from local barometric pressure to the pressure altitude setting of 29.92 inches of mercury as the aircraft ascends through the predetermined transition altitude and conversely, when the altimeter reference is changed in the opposite direction when the aircraft crosses the transition altitude on descent. This change in altimeter reference normally takes place at 18,000 feet as the aircraft climbs or descends between altitudes near the ground and the cruise altitudes. Conventional RNAV systems utilizing straight line and constant flight path angle navigation experience a discontinuity in the vertical steering error when the barometric (baro) setting is changed due to the resulting change in the apparent altitude of the aircraft. This discontinuity causes the pilot to again disconnect the conventional RNAV system and manually maneuver the aircraft through the discontinuity from the one path to the other. Alternatively, the undesirable piloting technique of slowly changing the barometric reference so that the aircraft gradually transitions from one path to the other is utilized in the prior art systems.

Brief Summary Text (8):
An additional problem in the vertical steering control of conventional RNAV systems occurs when the aircraft descends from cruise altitude to the terminal area of an airport because of the necessity of the descending aircraft to decelerate from cruise speed to terminal area speeds during the descent to the airport. U.S. aviation regulatory agencies typically require a deceleration to 250 knots by the time the aircraft descends to 10,000 feet. Typical jet transports are generally incapable of effecting this deceleration on normal descent flight paths by merely reducing thrust. Since generally a minimum thrust is required to maintain cabin pressurization, the pilot conventionally reduces the rate of descent by decreasing the descent angle until the speed is sufficiently reduced and then resumes the descent. By the time the aircraft decelerates to the required airspeed the aircraft acquires a significant altitude error and is generally not capable of reducing the error to zero by the time the waypoint is reached. In order to perform this manual maneuver the pilot must disconnect the automatic flight control system (AFCS) from the RNAV system and/or ignore the flight director commands. Additionally with conventional RNAV systems that provide only straight line flight paths, an additional waypoint must be inserted at the transition altitude to permit the level flight path section for the deceleration, thus introducing an undesired complexity.

Brief Summary Text (10):
The invention comprises apparatus for providing continuous vertical path control of the aircraft effecting optimum aircraft performance without disconnecting the AFCS from the RNAV system and without requiring time critical pilot inputs. The invention is in an RNAV system and comprises apparatus for controlling the vertical steering of the aircraft to maintain a predetermined reference airspeed as the aircraft ascends or descends to a waypoint with an "at-or-above" or an "at-or-below" altitude requirement. A pilot alert device is actuated when the aircraft is not at least making good the straight line path from the aircraft to the waypoint altitude at the waypoint. The invention further includes apparatus for providing vertical flight path angle commands that steer the aircraft from first to second waypoint altitudes through the transition altitude whereat the altimeter barometric reference is changed between local barometric altitude and pressure altitude to provide a smooth vertical path without a discontinuity at the transition altitude. The invention further includes apparatus for computing a deceleration zone and vertical flight path angles to permit the aircraft to decelerate to terminal area speeds as the craft descends to the transition altitude at which a maximum airspeed is permitted while making good the required waypoint altitudes.

Drawing Description Text (11):
FIG. 15 is a vertical flight path diagram illustrating the vertical flight path flown

in accordance with the invention for aircraft deceleration during a descent;

Drawing Description Text (12):
FIG. 16 is a schematic block diagram illustrating apparatus for controlling the vertical flight path for aircraft deceleration during a descent;

Drawing Description Text (14):
FIG. 18 is a program flow diagram of the computations performed by the embodiments of FIG. 17 for controlling the vertical steering of the aircraft when ascending or descending to a waypoint with an "at-or-above" or "at-or-below" altitude requirement.

Drawing Description Text (15):
FIG. 19 is a program flow diagram of the computations performed by the embodiment of FIG. 17 for providing the vertical path control when the aircraft is ascending or descending through the pressure-barometric altitude transition; and

Drawing Description Text (16):
FIG. 20 is a program flow diagram of the computations performed by the embodiments of FIG. 17 for providing the vertical path control for permitting the aircraft to decelerate during a descent.

Detailed Description Text (2):
Referring to FIG. 1, a conventional vertical flight path effecting point-to-point navigation is illustrated. The conventional RNAV system connects a waypoint A having a selected altitude H.sub.A to a waypoint B having a selected altitude H.sub.B utilizing a straight line 10. The system conventionally computes the angle .alpha..sub.1 which defines the straight line. The aircraft is controlled primarily in accordance with the deviation and deviation rate of the aircraft above or below the line 10 through an autopilot or through a flight director indicator, such as taught in U.S. Pat. No. 2,613,352. FIG. 2 illustrates a modification of the point-to-point navigation of FIG. 1 in which the point at which the desired altitude H.sub.B is attained is modified by an along track offset Y.sub.B. This permits the selected altitude to be attained ahead of or beyond the waypoint B by the selected distance Y.sub.B. The RNAV system computes in a manner similar to that described with respect to FIG. 1 the appropriate angle .alpha..sub.2 for the straight line navigation. FIG. 3 illustrates a further modification of the point-to-point navigation of FIG. 1 in which a preselected vertical angle .alpha..sub.3 is utilized instead of the computed angles .alpha..sub.1 or .alpha..sub.2 of FIGS. 1 and 2 respectively. This permits the pilot to select a desired flight path angle such as three degrees down on, for an example, an approach. In the typical point-to-point flight paths graphically illustrated in FIGS. 1, 2 and 3 as well as in the special-case flight paths of FIGS. 11, 12 and 15 of the present invention, the steering signal .theta..sub.c supplied to the pitch axis of the autopilot an/or the vertical guidance pointer of the flight director is generated from a signal proportional to the deviation .DELTA.H of the aircraft, from the computed straight line flight path defined by the vertical angle .alpha., and a damping term proportional to the rate of change of the deviation .DELTA.H in accordance with the general relationship

Detailed Description Text (3):
where K is a gain factor which may include a function of aircraft velocity for g-limiting purposes. Also, an accurate .DELTA.H term may be computed as a function of altitude rate from an air data computer, the vertical angle .alpha. and craft ground speed V.sub.G.

Detailed Description Text (4):
In connection with the "at-or-above" or "at-or-below" flight paths of FIGS. 4, 5, 6 and 7 generated in accordance with the present invention by the apparatus of FIG. 9, the steering signal is a pitch command .theta..sub.c based primarily on the error between a reference airspeed (or Mach) and the actual airspeed (or Mach), and not on a reference flight path. However, when the waypoint is not defined as "at-or-above or "at-or-below", this waypoint-referenced flight path is provided by a conventional vertical steering computer 38 responsive to the parameters illustrated, viz. aircraft altitude, H.sub.AC, waypoint altitude H.sub.W, ground range D to the waypoint, and any along track offsets. The instantaneous craft altitude on this straight line flight path is computed in accordance with the generalized relationship,

Detailed Description Text (9):
D is the distance from the aircraft to the waypoint.

Detailed Description Text (10):
Also computed within the "conventional vertical steering computer" 38 of FIG. 9, the steering signal .theta..sub.c is produced using in conjunction with the above parameters, aircraft actual altitude, aircraft altitude rate and flight path angle rate data, in accordance with the generalized steering signal relation set forth above.

Detailed Description Text (11):
In connection with the transition flight paths of FIGS. 11, 12 and 15 generated in accordance with the present invention by the apparatus of FIGS. 13 and 16 respectively, the steering signal is a pitch command .theta..sub.c based on aircraft deviation from a plurality of straight line or reference flight paths determined from waypoint data and data relating to the particular transition being transversed. These flight paths and steering signals are computed by the flight path and steering signal computers 75 and 76 shown in FIGS. 13 and 16, respectively.

Detailed Description Text (12):
For example, with respect to the baro-to-pressure altitude transition, two straight line flight paths are computed, one referenced to a pre transition flight path angle and distance to the approached waypoint and one referenced to a post transition flight path angle and distance to the approached waypoint. The flight path and steering signal computer 75 of FIG. 13 provides the flight path reference signals generally in accordance with the following relationships for an ascent through transition altitude graphically illustrated in FIG. 11 (for descent the relationships are obviously similar):

Detailed Description Text (15):
.alpha..sub.A and .alpha..sub.B are pre transition and post transition flight path angles respectively

Detailed Description Text (21):
Having thus computed the desired altitude H.sub.D, the H.sub.D error or .DELTA.H.sub.D required for the generation of the steering signal is produced simply by comparing it with the actual altitude H.sub.AC of the aircraft. The .DELTA.H.sub.D damping term is developed as explained above. Thus, the output of the steering computer of FIG. 13 is now acceptable to the aircraft autopilot and to the flight director horizontal pointer control. The .DELTA.H.sub.D signal, the craft deviation from the straight line flight path may be displayed on the glide slope pointer of the flight director indicator ADI, and/or horizontal situation indicator, HSI if desired.

Detailed Description Text (22):
With respect to the descent speed-reduction transition flight path of FIG. 15, from cruise altitude to a predetermined altitude at a predetermined waypoint, three distant straight line flight paths are computed. One is at a first angle .DELTA..sub.B from a descent initiated waypoint at cruise altitude H.sub.A to a predetermined deceleration-initiate altitude H.sub.DECEL at a first distance (D.sub.TOTAl - D.sub.A) from the approached waypoint B; another flight path at a second angle .alpha..sub.T from H.sub.DECEL to the transition altitude H.sub.TRANS (typically 10,000 ft) at a second distance(D.sub.TOTAL - D.sub.TRANS) from the approached waypoint during which speed is bled off such that at the transition altitude craft speed is a predetermined low value (typically 250 knots); and a third flight path at a third angle, which is equal to the first angle .alpha..sub.B, to the waypoint B altitude H.sub.B. The flight path and steering signal computations block 76 of FIG. 16 computes the aircraft deviation from each of these transition flight paths in the same manner as in FIG. 13 and the craft steering signal is also similarly computed. For example, the instantaneous desired altitude of the craft on the first descent flight path is determined in accordance with the general relationship:

Detailed Description Text (35):
Again, having computed the desired instantaneous altitude H.sub.D for the three flight path sectors, aircraft deviation therefrom is simply derived by comparing this desired

altitude with the actual aircraft altitude H.sub.AC. The steering signal .theta..sub.c is generated as above with respect to FIG. 13.

Detailed Description Text (37):
Referring to FIGS. 4, 5, 6 and 7, acceptable flight paths in accordance with the invention for "at-or-above" and "at-or-below" designated waypoints are illustrated. In FIG. 4 in which the aircraft ascends from the altitude H.sub.A of the waypoint A to at-or-above the altitude H.sub.B at the waypoint B, typical acceptable paths are illustrated which have flight path angles greater than the minimum flight path angle of the straight line path 11. It is appreciated that the flight path 11 represents the boundary of the acceptable flight paths for ascending to "at-or-above" the altitude H.sub.B of the waypoint B. Under the conditions illustrated in FIG. 4 the flight path 11 has a minimum boundary flight path angle associated therewith as well as a minimum boundary altitude rate. FIG. 5 illustrates a boundary flight path 12 as well as typical acceptable flight paths for descending from the altitude H.sub.A of the waypoint A to "at-or-above" the altitude H.sub.B of the waypoint B. It will be appreciated that the boundary flight path 12 has a minimum acceptable flight path angle and a minimum acceptable altitude rate associated therewith. FIG. 6 illustrates typical acceptable flight paths and a boundary flight path 13 for an aircraft ascending from the altitude H.sub.A at the waypoint A to "at-or-below" the altitude H.sub.B at the waypoint B. The boundary flight path 13 has a maximum flight path angle and a maximum altitude rate associated therewith. Similarly, FIG. 7 illustrates typical acceptable flight paths and a boundary flight path 14 for an aircraft descending from the altitude H.sub.A at the waypoint A to "at-or-below" the altitude H.sub.B at the waypoint B. The boundary flight path 14 has a maximum acceptable flight path angle and a maximum acceptable altitude rate associated therewith. It will be appreciated with respect to FIGS. 4, 5, 6 and 7 that the flight path angle and altitude rates discussed are signed quantities where ascending quantities are positive and descending quantities are negative. Thus, for example, in FIG. 5 the minimum flight path angle of the boundary flight path 12 is more negative than the flight path angles of the acceptable paths.

Detailed Description Text (38):
Referring now to FIG. 8, the vertical navigation parameters utilized in controlling an aircraft 15 on the desired flight path are illustrated. The aircraft 15 is depicted at an instantaneous altitude H.sub.AC with an indicated airspeed of V.sub.AC and approaching a waypoint 16 having an altitude of H.sub.W. The straight line 17 from the aircraft 15 to the waypoint 16 constitutes the boundary of acceptable paths with a boundary flight path angle of .alpha..sub.0. The aircraft 15 is illustrated at a lateral distance D from the waypoint 16 with an instantaneous flight path angle of .alpha..sub.AC.

Detailed Description Text (39):
In accordance with the invention, the aircraft 15 is controlled to ascend or descend at a specified indicated airspeed (IAS) to a "soft" altitude "at-or-above" +or "at-or-below" the waypoint altitude H.sub.W. "At-or-above" defines the aircraft 15 crossing the waypoint 16 at a minimum altitude with any altitude above the minimum altitude acceptable. "At-or-below" denotes the aircraft 15 crossing the waypoint 16 at a maximum altitude with any altitude below the maximum altitude being acceptable. These "soft"soft" altitude requirements are utilized with regard to the invention as compared to a "hard" altitude requirement where the aircraft 15 must cross the waypoint 16 "at" the altitude H.sub.W. The optimum indicated airspeed for the maneuver (V.sub.REF) may be selected manually by the pilot or automatically in a manner to be explained. The airspeed may alternatively be controlled to a Mach number with regard to a reference Mach number M.sub.REF. The invention provides a pilot alert warning if the selected IAS and resulting flight path angle are not sufficient to meet the altitude requirements.

Detailed Description Text (40):
Referring now to FIG. 9, a schematic block diagram of apparatus for vertical flight path control in ascending or descending to waypoints with "at-or-above" or "at-or-below" altitude requirements in accordance with the invention is illustrated. The apparatus of FIG. 9 includes a plurality of function blocks that may be instrumented by any of a variety of well known devices. For example, the function blocks may be instrumented by special purpose discrete analog or digital circuits or

may alternatively be implemented by general purpose digital or analog computation apparatus. The circuits of FIG. 9 may be instrumented in a manner similar to that described in co-pending U.S. patent application Ser. No. 581,987, filed May 29, 1975, in the names of William C. Post and Edmond E. Olive, entitled "Steered Lateral Course Transition Control For Aircraft Area Navigation System" or in co-pending U.S. patent application Ser. No. 581,988, filed May 29, 1975, in the names of Donald H. Baker, Larry J. Bowe and William C. Post, entitled "Helical Vertical Path Control For Aircraft Area Navigation System", both applications being assigned to the present assignee.

Detailed Description Text (41):
A conventional air data system 20 provides signals V.sub.AC, M.sub.AC, H.sub.AC, TAS and H.sub.AC representative of the aircraft indicated airspeed, the aircraft Mach number, the aircraft altitude, the aircraft true airspeed and the aircraft altitude rate respectively. The apparatus further includes a VOR receiver 21 for providing the VOR bearing .OMEGA. and a DME receiver 22 for providing the DME distance R in response to signals from a VORTAC as explained in said Ser. No. 582,987 and Ser. No. 581,988. The apparatus further includes a compass system 23 for providing aircraft heading HDG in a conventional manner.

Detailed Description Text (42):
The apparatus of FIG. 9 also includes a computer 24 for storing the navigational and waypoint associated data with respect to the flight plan of the aircraft. For example, the computer 24 may be preloaded prior to a particular flight with the geographical locations, associated altitudes and associated data of all of the waypoints along the flight plan as well as the locations of the associated VORTACs. The computer 24 is arranged in a conventional manner to provide the required data as the aircraft executes the flight plan with respect to the sequentially encountered waypoints.

Detailed Description Text (44):
The computer 24 provides signals V.sub.REV and M.sub.REF representative of the reference indicated airspeed and the reference Mach number respectively. These quantities may be entered by the pilot via the device 25 of alternatively, may be initialized with respect to the current aircraft airspeed at the time the associated system mode is selected should the pilot fail to command a different speed. The computer 24 also provides a signal M.sub.O defining a boundary Mach number above which Mach is used and below which indicated airspeed is utilized for providing the steering commands in a manner to be described. M.sub.O is a prestored computer constant representative of the specific aircraft type in which the system is installed.

Detailed Description Text (45):
Since the optimum climb of the aircraft controlled by the apparatus of FIG. 9 is not to a fixed path, an altitude error is displayed in a manner to be described which is the difference between the aircraft altitude H.sub.AC from the air data system 20 and the first firm altitude specified for a subsequent waypoint in the flight plan. This firm altitude (not at-or-above or at-or-below) is the altitude to which the climb or descent is being flown. The first firm altitude is provided by the H.sub.FIRM signal from the computer 24. This capability is utilized, for example, when the aircraft climbs from a departure airport to cruise altitude along a flight path defined by a sequence of waypoints having altitudes at which the aircraft is required to cross at-or-above in its climb to the first waypoint at the cruise altitude.

Detailed Description Text (47):
As previously described, the computer 24 may be preloaded prior to a particular flight with all of the data relating to the waypoints of the flight plan as well as the data relating to the aircraft characteristics. As previously discussed, the computer 24 is arranged in a conventional manner to provide the above discussed prestored data as the aircraft executes the flight plan with regard to the sequentially encountered waypoints. The above discussed parameters V.sub.REF and M.sub.REF may also be altered by the pilot via the data input device 25 in accordance with pilot preferences.

Detailed Description Text (48):
The .theta. and r signals from the computer 24 as well as the .OMEGA. and R signals from the VOR and DME receivers 21 and 22 respectively, are applied to a function block 26 to provide the north and east coordinates NAW and EAW respectively of the aircraft

with respect to the waypoint that the aircraft is approaching. The function block 26 performs a well known function F.sub.1 for converting the aircraft, waypoint and VORTAC bearing and distance data to the NAW and EAW coordinates. The function F.sub.1 may be implemented in the manner described in said Ser. No. 581,987 and Ser. No. 581,988. The VOR and DME data from the receivers 21 and 22 are also applied to a function block 27 wherein conventional circuitry implementing a function F.sub.2 provides the ground speed V.sub.G of the aircraft. It will be appreciated that aircraft heading (HDG) from the compass system 23 and true airspeed (TAS) from the air data system 20 may be utlized as inputs to the function block 27 thereby generating a current and accurate value of the ground speed V.sub.G. The function F.sub.2 of the block 27 may be implemented as disclosed in U.S. patent application Ser. No. 465,228 filed Apr. 29, 1974 in the names of Donald H. Baker and Larry J. Bowe, entitled "Radio Navigation System" and assigned to the assignee of the present invention.

Detailed Description Text (49):
The NAW and EAW signals from the function block 26, as well as the .psi..sub.1 signal from the computer 24 are applied to a function block 30. The function block 30 provides a signal D representative of the distance of the aircraft to the waypoint in accordance with a function F.sub.3. The function block 30 provides the distance D based on the north and east coordinates of the aircraft with respect to the waypoint (NAW, EAW) and the inbound course .psi..sub.1, in accordance with functional relationships that are well known in the RNAV art, and will not be further described herein for brevity. The distance parameter D is as illustrated in FIG. 8.

Detailed Description Text (50):
The distance signal D from the function block 30, the aircraft altitude signal H.sub.AC from the air data system 20 and the waypoint altitude signal H.sub.W from the computer 24 are applied to a function block 31 to generate an .alpha..sub.O signal representative of the vertical angle of the boundary flight path 17 (FIG. 8) in accordance with a function F.sub.4 as follows: ##EQU1## where

Detailed Description Text (52):
The aircraft computed ground speed V.sub.G and the aircraft altitude rate signal H.sub.AC from the air data system 20 are applied to a function block 32 to generate an .alpha..sub.AC signal representative of the aircraft instantaneous flight path angle in accordance with a function F.sub.5 as follows: ##EQU2## where the altitude rate ##EQU3##

Detailed Description Text (53):
The waypoint altitude signal H.sub.W from the computer 24, the aircraft altitude signal H.sub.AC from the air data system 20, the distance signal D from the function block 30 and the ground speed signal V.sub.G from the function block 27 are applied to a function block 33 to generate a signal H.sub.O representative of the altitude rate on the boundary flight path (i.e., flight path 17 of FIG. 8) in accordance with a function F.sub.6 as follows: ##EQU4## where .DELTA.H = H.sub.W - H.sub.AC, H.sub.O is in feet per minute, .DELTA.H is in feet, V.sub.G is in knots, D is in nautical miles and K is set at 60 for the conditions described.

Detailed Description Text (54):
The .alpha..sub.AC signal representative of the actual flight path angle of the aircraft from the function block 32 and the .EPSILON..sub.O signal representative of the flight path angle of the boundary flight path from the function block 31 as well as the waypoint data signal from the computer 24 are applied to a compare block 34. The compare block 34 provides an output to a conventional pilot alert device 35 as well as an output on a lead 36 to enable conventional vertical steering. As previously discussed, the waypoint data signal from the computer 24 is representative of whether the waypoint is of the "at-or-above" or the "at-or-below" type. The compare block 34 is instrumented with conventional logic circuitry to actuate the pilot alert device 35 when .alpha..sub.AC is algebraically less than .alpha..sub.O and the waypoint is of the "at-or-above" variety. The compare block 34 further includes conventional logic circuitry for enabling the pilot alert device 35 when .alpha..sub.AC is algebraically greater than .alpha..sub.O and the waypoint is of the "at-or-below" variety. When the waypoint is neither an "at-or-above" or an "at-or-below" waypoint, the waypoint data signal from the computer 24 causes the logic circuitry of the compare block 34 to enable the conventional vertical steering of the aircraft via the lead 36 as

illustrated in FIG. 9. It will be appreciated that the logic functions described are readily implemented with conventional combinational logic configurations. It will furthermore be appreciated from FIGS. 4, 5, 6 and 7 that when the aircraft is not making good an acceptable flight path, the compare circuitry of the block 34 will enable the pilot alert device 35 thereby alerting the pilot that corrective action is required.

Detailed Description Text (55):
In the present embodiment of the invention the block 34 compares the actual aircraft flight path angle .alpha..sub.AC with the boundary flight path angle .alpha..sub.O to provide a pilot alert. Alternatively, the block 34 may instead compare actual altitude rate H.sub.AC from the air data system 20 with the boundary altitude rate H.sub.O from the function block 33 to provide the pilot alert in a manner similar to that described with respect to the flight path angle comparison. For convenience, the boundary parameters .alpha..sub.O and H.sub.O from the blocks 31 and 33 respectively are displayed to the pilot on a conventional display device 37.

Detailed Description Text (56):
The aircraft actual airspeed signal V.sub.AC from the air data system 20 and the reference airspeed signal V.sub.REF from the computer 24 are applied to a summing junction 40 to provide a .DELTA.V signal representative of the difference therebetween. In a similar manner the aircraft Mach number signal M.sub.AC from the air data system 20 and the reference Mach number M.sub.REF from the computer 24 are applied to a summing junction 41 to provide a .DELTA.M signal representative of the difference therebetween. The .DELTA.V and .DELTA.M signals are applied through respective gain blocks 42 and 43 to a selection block 44. The gain blocks 42 and 43 multiply the .DELTA.V and .DELTA.M signals by gain constants G.sub.1 and G.sub.2 respectively in accordance with the control authority desired. A compare block 45 receives inputs from the aircraft Mach number signal M.sub.AC from the air data system 20 and the prestored computer Mach constant M.sub.O from the computer 24 and controls the selection circuit 44 to connect the velocity signal to an output lead 46 when M.sub.Ac <M.sub.O and to connect the Mach number signal to the output lead 46 when M.sub.AC .gtoreq.M.sub.O.

Detailed Description Text (57):
Thus pitch steering commands .theta..sub.c proportional to speed error are applied via the lead 46 and suitable select matrix 48 to the pitch channel of an automatic flight control system (AFCS) 47 which controls the pitch attitude of the aircraft via the pitch attitude control surfaces 50. The pitch steering commands on the lead 46 are preferably or alternatively also applied to the aircraft flight director system 51 which controls the vertical steering or pitch command bar 52 of the attitude director indicator (ADI) of the flight director system. The flight director 51 includes conventional damping terms such as velocity rate or Mach rate and/or pitch attitude as taught in U.S. Pat. No. 2,613,352. Also, the select matrix 48 is controlled by the conventional steering logic signal on lead 36, as required to switch into the autopilot and/or flight director the conventional steering signal from the conventional steering computation 38 as illustrated. Thus, above a Mach number of M.sub.O the difference between actual Mach M.sub.AC and reference Mach M.sub.REF provides the vertical pitch steering signals whereas below M.sub.O the difference between actual indicated airspeed V.sub.AC and the reference indicated airspeed V.sub.REF is utlized to provide the steering signals. A typical value for M.sub.O for modern jet transports is 0.78 Mach. Typically the aircraft is controlled to achieve the desired speed V.sub.REF or M.sub.REF by commanding a pitch up attitude change when .DELTA.V or .DELTA.M is positive and a pitch down attitude change when .DELTA.V or .DELTA.M is negative. The commands are presented to the pilot through the flight director command bar 52 on the ADI or control is automatic via the AFCS 47. When the .DELTA.V signal is utilized, a typical pitch authority for jet transports is:

Detailed Description Text (58):
where PITCH COMMAND is in degrees and .DELTA.V is in feet per second. Thus it is appreciated that the constant G.sub.1 of the gain block 42 is equal to 0.352 in this instance. In a similar manner when the aircraft is controlled to Mach number, then a typical pitch authority for jet transports is:

Detailed Description Text (59):

where the PITCH COMMAND is again in degrees. It will be appreciated therefore that the constant G.sub.2 of the gain block 43 will be equal to 215 in this instance. Thus, as the aircraft ascends or descends to a waypoint with an "at-or-above" or "at-or-below" designation, the pitch steering commands are generated proportional to speed error with regard to the selected airspeed V.sub.REF or the selected Mach number M.sub.REF.

Detailed Description Text (60):
The aircraft altitude signal H.sub.AC from the air data system 20 and the H.sub.FIRM signal from the computer 24 are applied to a summing junction 53 to provide an altitude error signal representative of the difference therebetween. The altitude error signal is applied to the glide slope vertical deviation indicator 54 of the aircraft horizontal situation indicator (HSI) or of the ADI of the flight director system. Thus, it is appreciated that the altitude error is displayed to the pilot in much the same manner as glide slope deviation is displayed during an instrument landing approach. Since the optimum climb or descent as described hereinabove is not to a fixed path, the altitude error displayed is the difference between the aircraft altitude H.sub.AC and the first firm altitude H.sub.FIRM specified for a subsequent waypoint in the flight plan. This firm altitude is that to which the ascent or descent is being flown. It will be appreciated that for conventional steering as controlled by the lead 36 and the switching matrix 48, conventional deviation signals as discussed above are applied to the glide slope indicator 54 from the computer 38.

Detailed Description Text (61):
The capability of the apparatus of FIG. 9 to control the aircraft to a selected speed (IAS or Mach) may also be utilized by the RNAV system to transition between discontinuous flight paths. Referring to FIG. 10, a situation is illustrated where the selected altitude H.sub.B and the flight path angle .alpha..sub.B for waypoint B define a flight path that is not continuous with altitude H.sub.A at waypoint A. The discontinuity is flown under speed control as described hereinabove with the altitude error computed to the desired flight path to waypoint B. It is appreciated that other examples of discontinuities may be defined for ascents or descents and are flown in a similar manner.

Detailed Description Text (62):
As discussed hereinabove with respect to conventional RNAV systems, a flight path discontinuity is often experienced when the aircraft crosses the transition altitude below which the aircraft altitude is referenced to baro-corrected altitude (local baro setting) and above which the aircraft altitude is referenced to standard pressure altitude (29.92 baro setting) as the aircraft transitions between the waypoints of the flight plan. The present invention permits ascent and descent through the transition altitude by recomputing the flight path vertical angles with regard to the transition altitude crossing to provide continuous navigation without flight path discontinuities. As is known, the aircraft barometric altimeter is set with the local barometric pressure below the transition altitude and with the standard setting of 29.92 inches of mercury above the transition altitude. In U.S. domestic airspace the transition altitude is generally 18,000 feet. It will be appreciated that conventional air data systems typically provide pressure altitude data to the RNAV system at all times. When the aircraft is below the transition altitude this data is corrected to baro altitude in the pilot's altitude indicator or in the RNAV system in accordance with well known air data equations relating altitude correction to baro setting. For this purpose the local baro setting is provided as an input to the RNAV system from an external manually set device or through the pilot manual data input to the RNAV computer to permit the RNAV system to perform the altitude calculation.

Detailed Description Text (63):
Referring to FIG. 11, a vertical flight path diagram illustrates vertical navigation parameters with respect to ascending through the barometric to pressure altitude transition in accordance with the invention. The aircraft approaches a waypoint A defined at baro corrected altitude H'.sub.A and is to ascend through the transition altitude to a waypoint B defined at pressure altitude or flight level H.sub.B. Since the waypoint A is below the transition altitude, the waypoint altitude H'.sub.A is conveniently stored in terms of thousands of feet. For example, if the waypoint A has an altitude H'.sub.A of 13,000 feet, then H'.sub.A will be stored as 13,000 feet. Since the waypoint B is above the transition altitude the waypoint altitude H.sub.B is conveniently stored as a flight level. For example, if the waypoint altitude H.sub.B

is at a pressure altitude of 33,000 feet, then flight level 330 is stored as the H.sub.B altitude of the waypoint. In a manner to be described hereinafter, the RNAV system computes an apparent waypoint B at a baro corrected altitude H'.sub.B numerically equal to the pressure altitude H.sub.B. For example, if H.sub.B is at flight level 330, then H'.sub.B is 33,000 feet. It will be appreciated that the apparent waypoint B will generally be physically displaced vertically from the waypoint B by the altitude correction for the specific baro setting and altitude.

Detailed Description Text (64):
The angle .alpha..sub.A is the vertical flight path angle which, if flown, would bring the aircraft to baro altitude H'.sub.B at apparent waypoint B. This is the path that the aircraft is constrained to fly below the transition altitude, the path terminating a distance D.sub.A from the waypoint A where the path intersects the transition altitude. D.sub.TOTAL is the lateral distance between the waypoint A and the waypoint B and D.sub.B is the difference between D.sub.TOTAL and D.sub.A. The angle .alpha..sub.A is computed as follows: ##EQU5## The distance D.sub.A is computed as follows: ##EQU6## Upon attaining the distance D.sub.A from the waypoint A, a new vertical angle .alpha..sub.B is computed based on the remaining distance D.sub.B to the waypoint B and the difference between the waypoint B pressure altitude H.sub.B and the pressure altitude H'.sub.TRANS equivalent to the transition altitude H.sub.TRANS as follows: ##EQU7## The aircraft is controlled to the flight path defined by the vertical angles .alpha..sub.A and .alpha..sub.B as it flies from the waypoint A to the waypoint B.

Detailed Description Text (65):
Referring now to FIG. 12, a vertical flight path diagram illustrates identical navigation parameters with respect to descending through the pressure to barometric altitude transition in accordance with the invention. The aircraft approaches a waypoint A at a pressure altitude of H.sub.A and must descend to a waypoint B through the transition altitude attaining a baro corrected altitude H'.sub.B. The path below the transition is determined by computing the flight path angle .alpha..sub.B for the apparent waypoint A at which the flight level H.sub.A is interpreted as a numerically equal baro altitude H'.sub.A. .alpha..sub.B is computed as follows: ##EQU8## where D.sub.TOTAL = D.sub.A + D.sub.B in the manner described with respect to FIG. 11. It is appreciated that the considerations with respect to flight level pressure altitude, baro altitude and transition altitude as well as the distances D.sub.A and D.sub.B discussed with regard to FIG. 11 also apply to the conditions of FIG. 12.

Detailed Description Text (66):
The point at which the flight path defined by .alpha..sub.B crosses the transition altitude is computed as follows: ##EQU9## The RNAV system then computes the angle .alpha..sub.A for the proper flight path for the aircraft to attain the transition altitude at the desired point defined by D.sub.A. The angle .alpha..sub.A is computed from the pressure altitude H'.sub.TRANS equivalent to the transition altitude, the pressure altitude H.sub.A of the waypoint A and the distance D.sub.A as follows: ##EQU10## The angle .alpha..sub.A is flown from the waypoint A until the aircraft reaches the point D.sub.A from the waypoint A and subsequently the angle .alpha..sub.B is flown to attain the waypoint B at the baro corrected altitude H'.sub.B.

Detailed Description Text (68):
The computer 24 further provides a signal D.sub.TOTAL representative of the prestored distance between the waypoints A and B as illustrated in FIGS. 11 and 12. The computer 24 additionally provides signals .psi..sub.1, .theta. and r representative respectively of the inbound course to the waypoint, the bearing of the waypoint with respect to the associated VORTAC and the range of the waypoint with respect to the associated VORTAC in a manner similar to that described above with respect to FIG. 9. It will be appreciated that with respect to the flight paths of FIGS. 11 and 12, the .psi..sub.1, .theta. and r quantities are provided with respect to the waypoint B, i.e., the waypoint to which the aircraft is on an inbound course. The computer 24 also provides the Y.sub.B signal as described above.

Detailed Description Text (69):
The apparatus of FIG. 13 additionally includes the VOR receiver 21 and the DME receiver 22 as discussed above with respect to FIG. 9. The VOR receiver 21 provides the signal .OMEGA. and the DME receiver 22 provides the signal R representative

respectively of the bearing and range of the aircraft with respect to the VORTAC to which the receivers 21 and 22 are automatically tuned by the flight plan program.

Detailed Description Text (70):
In a manner similar to that described above with respect to FIG. 9, the .theta. and r signals from the computer 24 as well as the .OMEGA. and R signals from the VOR and DME receivers 21 and 22 respectively are applied to the function block 26 to provide the north and east coordinates NAW and EAW respectively of the aircraft with respect to waypoint B that the aircraft is approaching. Again, in a manner similar to that described above with respect to FIG. 9, the NAW and EAW signals from the function block 26 as well as the .psi..sub.1 signals from the computer 24 are applied to the function block 30 that provides a signal representative of the distance of the aircraft to the waypoint B being approached. The output from the function block 30 and the D.sub.TOTAL signal from the computer 24 are applied to a summing junction 55 to provide a D.sub.1 signal representative of the distance of the aircraft from the waypoint A. This is appreciated from the flight path geometry illustrated in FIGS. 11 and 12.

Detailed Description Text (72):
The H.sub.A signal, the H.sub.B signal and the D.sub.TOTAL signal are applied to a function block 60 to generate an .alpha..sub.A signal representative of the flight path angle .alpha..sub.A of FIG. 11 in accordance with a function F.sub.7 as follows: ##EQU11## It will be appreciated, as discussed above, that H.sub.B and H'.sub.B as well as H.sub.A and H'.sub.A have numerically equal values with respect to each other. The unprimed quantities represent waypoint altitudes above the transition altitudes expressed as pressure altitude or flight level. The primed quantities represent waypoint altitudes below the transition altitude expressed as barometrically corrected altitude.

Detailed Description Text (74):
The D.sub.A signal from the function block 61, the H'.sub.TRANS signal from the summing junction 57 as well as the H.sub.B and D.sub.TOTAL signals from the computer 24 are applied to a function block 62 to generate an .alpha..sub.B signal representative of the flight path angle .alpha..sub.B of FIG. 11 in accordance with a function F.sub.9 as follows: ##EQU13##

Detailed Description Text (77):
The D.sub.A signal from the function block 64, the H'.sub.TRANS signal from the summing junction 57 and the H.sub.A signal from the computer 24 are applied to a function block 65 to generate an .alpha..sub.A signal representative of the flight path angle .alpha..sub.A of FIG. 12 in accordance with a function F.sub.12 as follows: ##EQU16##

Detailed Description Text (79):
The outputs from the compare circuits 66, 67 and 70 as well as the D.sub.A signals from the function blocks 61 and 64 are applied to selection logic 71. The selection logic 71 comprises conventional circuitry for selecting the D.sub.A signal from either the block 61 or from the block 64 and applying the selected signal to its output in accordance with the binary states of the compare circuits 66, 67 and 70. When H'.sub.B is greater than H.sub.TRANS and H'.sub.A is less than H.sub.TRANS, the D.sub.A signal from the function block 61 is routed to the output of the select circuit 71. These are the conditions illustrated in FIG. 11 and thus it is appreciated that the aircraft is ascending from the waypoint A to the waypoint B through the transition altitude. Therefore, the value of D.sub.A as illustrated in FIG. 11 and provided by the function block 61 is utilized.

Detailed Description Text (80):
When H'.sub.B is not greater than H.sub.TRANS and H'.sub.A is greater than H.sub.TRANS, the D.sub.A signal from the function block 64 is selected and routed to the output of the select circuit 71. These are the conditions illustrated in FIG. 12 and thus it is appreciated that the aircraft is descending from the waypoint A to the waypoint B through the transition altitude. Therefore, the value of D.sub.A as illustrated in FIG. 12 and provided by the function block 64 is utilized. The selected D.sub.A signal from the selection block 71 and the D.sub.1 signal from the summing junction 55 are applied to a comparison circuit 72 that provides a binary output

signal in accordance with D.sub.1 being greater than or equal to D.sub.A.

Detailed Description Text (81):
The binary output signals from the compare blocks 66, 67, 70 and 72 are applied as selection inputs to a selection matrix 73. The .alpha..sub.A signals from the function blocks 60 and 65 as well as the .alpha..sub.B signals from the function blocks 62 and 63 are applied as inputs to the selection matrix 73. A signal representative of the normal vertical angle utilized when the aircraft is not either ascending or descending through the transition altitude is applied to the selection matrix 73 via a lead 74. The selection matrix 73 selectively connects one of the inputs from the elements 60, 62, 63, 65 and 74 in accordance with the binary states of the comparison circuits 66, 67, 70 and 72. With reference to FIG. 11, when the aircraft is ascending through the transition altitude from the waypoint A to the waypoint B, H'.sub.B is greater than H.sub.TRANS, and H'.sub.A is less than H.sub.TRANS. Thus as discussed above, the D.sub.A value from the function block 61 is applied to the comparator 72 via the selection circuit 71. When the distance D.sub.1 of the aircraft from the waypoint A is not greater than or equal to D.sub.A and the comparisons between H'.sub.A and H'.sub.B with respect to H.sub.TRANS is as discussed with respect to the ascending situation of FIG. 11, the selection matrix 73 connects the .alpha..sub.A signal from the function block 60 to the output 46 where it is employed for the computation of the flight path deviation and steering signals as discussed above. Since, as discussed above, the function block 60 is utilized to compute the value of .alpha..sub.A as illustrated in FIG. 11, this angle will be controlling under the conditions specificed. If, however, D.sub.1 is greater than or equal to D.sub.A during the ascending situation of FIG. 11, the selection matrix 73 connects the .alpha..sub.B signal from the function block 62 to the output 46 so that the .alpha..sub.B flight path angle illustrated in FIG. 11 will be the controlling flight path angle reference.

Detailed Description Text (82):
Under the conditions of FIG. 12 when the aircraft is descending through the transition altitude, H'.sub.B is not greater than H.sub.TRANS and H'.sub.A is greater than H.sub.TRANS. Under these conditions when the distance D.sub.1 from the waypoint A is not greater than or equal to D.sub.A the .alpha..sub.A signal from the function block 65 is connected to the output 46 of the selection matrix 73. When, however, D.sub.1 is greater than or equal to D.sub.A the .alpha..sub.B signal from the function block 63 is connected to the output 46 of the selection matrix 73 in accordance with the conditions illustrated in FIG. 12.

Detailed Description Text (83):
When, however, H'.sub.B is greater than H.sub.TRANS and H'.sub.A is not less than H.sub.TRANS the aircraft is flying between two waypoints above the transition altitude and thus the normal vertical angle signal on the line 74 is connected to the output 46 of the selection matrix 73. Conversely, when H'.sub.B is not greater than H.sub.TRANS and H'.sub.A is not greater than H.sub.TRANS, the aircraft is flying between two waypoints below the transition altitude and again the normal vertical angle signal on the lead 74 is connected to the output 46 of the selection matrix 73.

Detailed Description Text (84):
In a manner similar to that described above with regard to FIG. 9, the output 46 is connected to the flight path and steering signal computer 75, the output .theta..sub.c of which is applied to the automatic flight control system 47 for automatically controlling the aircraft in accordance with the selected signals .alpha..sub.A and .alpha..sub.B via the pitch control surfaces 50. The output .theta..sub.c is also applied to the flight director 51 which controls the vertical steering pointer 52 of the ADI. The actual deviation of the craft from the path defined by .alpha..sub.A or .alpha..sub.b may also be applied to the glide slope indicator 54 on the HSI or the ADI to provide an indication to the pilot with respect to deviations of the aircraft above or below the selected flight paths illustrated in FIGS. 11 and 12 as defined by the flight path angles .alpha..sub.A and .alpha..sub.B. Thus it is appreciated that the apparatus of FIG. 13 computes the vertical flight path angles .alpha..sub.A or .alpha..sub.B which permit smooth flight through the baro transition altitude H.sub.TRANS.

Detailed Description Text (85):
Large jet transport aircraft typically descend from the enroute altitude at a

specified Mach or IAS. Air traffic regulations require that the enroute speed must be reduced so as not to exceed a maximum value V.sub.MAX by the time the aircraft attains a transition altitude H.sub.TRANS. For example, in domestic U.S. airspace the transition altitude is 10,000 feet and V.sub.MAX is 250 knots indicated airspeed. Modern jet transports cannot always achieve the required speed reduction by merely reducing thrust. Generally a minimum thrust is required to maintain cabin pressurization. Generally the aircraft deceleration begins at 14,000 feet to achieve the 250 knots IAS at 10,000 feet as required. The altitude of 14,000 feet is selected since it is the highest altitude where idle power can be utilized without loss of cabin pressurization. Since a minimum thrust is required to maintain cabin pressurization, in the prior art the pilot usually reduced rate of descent until the speed was sufficiently attenuated.

Detailed Description Text (86):
Referring now to FIG. 14, a vertical flight path diagram of a conventional flight path utilized in reducing airspeed during a descent illustrates how the above described prior art maneuver affects the vertical performance. The aircraft descending from a waypoint A at altitude H.sub.A to a waypoint B at altitude H.sub.B at a constant flight path angle so as to fly point-to-point along a straight line vertical flight path, reduces the rate of descent at 14,000 feet by executing a pitch up maneuver such that at 10,000 feet the IAS has been sufficiently reduced. It is appreciated from FIG. 14 that by the time the aircraft decelerates to the required IAS a significant altitude error is developed which the aircraft may not be capable of reducing to zero by the time the waypoint B is reached. As previously discussed, it is appreciated that the pilot must disconnect the AFCS from the RNAV system in order to perform this maneuver.

Detailed Description Text (87):
Referring now to FIG. 15, the vertical geometry for effecting the speed reduction in accordance with the invention is illustrated. A transition zone of length D.sub.TRANS is provided between a selected altitude H.sub.DECEL (typically the 14,000 feet altitude described above) and the transition altitude H.sub.trans (typically the 10,000 foot altitude as required) in which a shallow angle .alpha..sub.T is commanded to permit the aircraft to decelerate from its current airspeed V.sub.AC to the desired SPEED V.sub.MAX. In accordance with the invention the RNAV system computes the descent vertical angle .alpha..sub.B that permits the deceleration to be executed at the shallower transition angle .alpha..sub.T prior to reaching the transition altitude H.sub.TRANS. After decelerating in the transition zone the descent flight path angle .alpha..sub.B is resumed so that the aircraft crosses the waypoint B at the altitude H.sub.B.

Detailed Description Text (94):
Referring now to FIG. 16 in which like reference numerals indicate like components with respect to FIGS. 9 and 13, a schematic block diagram illustrating apparatus for effecting the vertical flight path control as illustrated in FIG. 15 when descending from the waypoint A to the waypoint B through the speed reduction transition altitude is illustrated. The apparatus of FIG. 16 includes a plurality of function blocks that may be instrumented in a manner similar to that described above with respect to FIGS. 9 and 13. The apparatus of FIG. 16 includes the air data system 20 that provides the V.sub.AC signal representative of the indicated airspeed of the aircraft as well as the H.sub.AC and H.sub.AC signal in the manner described above with respect to FIG. 9. The apparatus of FIG. 16 also includes the computer 24 as well as the pilot manual data input device 25 described above with respect to FIGS. 9 and 13. The computer 24 provides a plurality of signals representing prestored data for executing the flight path of FIG. 15, which data may be manually altered by the pilot via the device 25.

Detailed Description Text (95):
The computer 24 provides a signal V.sub.MAX representing the maximum speed below the speed reduction transition altitude. In domestic U.S. airspace V.sub.MAX is required to be 250 knots IAS. The computer 24 also provides a signal H.sub.TRANS representative of the transition altitude illustrated in FIG. 15. As discussed, this quantity is normally the constant value of 10,000 feet. The computer 24 further provides an aircraft performance parameter H.sub.DECEL representative of the altitude typically utilized to begin the deceleration. As discussed above, this altitude is typically selected as 14,000 feet. The computer 24 further provides waypoint parameter signals

D.sub.TOTAL, H.sub.B and H.sub.A representative of the prestored distance between the waypoints A and B, the altitude of the waypoint B and the altitude of the waypoint A respectively as illustrated in FIG. 15. The signals D.sub.TOTAL, H.sub.B and H.sub.A were discussed hereinabove with respect to FIG. 13 as provided by the computer 24 and are additionally utilized in the apparatus of FIG. 16. In a manner similar to that described above with respect to FIG. 13, the computer 24 provides the signals .psi..sub.1 .theta. and r representative respectively of the inbound course to the waypoint, the bearing of the waypoint with respect to the associated VORTAC and the range of the waypoint with respect to the associated VORTAC. It will be appreciated that with respect to the flight path of FIG. 15 the .psi..sub.1, .theta. and r quantities are provided with respect to the waypoint B, i.e., the waypoint to which the aircraft is on an inbound course. The computer 24 also provides the Y.sub.B signal as discussed above.

Detailed Description Text (96):
The apparatus of FIG. 16 additionally includes the VOR receiver 21 and the DME receiver 22 as discussed above with respect to FIGS. 9 and 13. The VOR receiver 21 provides the signal .OMEGA. and the DME receiver 22 provides the signal R representative respectively of the bearing and range of the aircraft with respect to the VORTAC to which the receivers 21 and 22 are tuned.

Detailed Description Text (97):
In a manner similar to that described above with respect to FIG. 13, the .theta. and r signals from the computer 24 as well as the .OMEGA. and R signals from the VOR and DME receivers 21 and 22 respectively are applied to the function block 26 to provide the north and east coordinates NAW and EAW respectively of the aircraft with respect to waypoint B that the aircraft is approaching. Again in a manner similar to that described above with respect to FIG. 13, the NAW and EAW signals from the function block 26 as well as the .psi..sub.1 from the computer 24 are applied to the function block 30 that provides the signal representative of the distance of the aircraft to the waypoint B being approached. Again as illustrated in FIG. 13 and described with respect thereto, the output from the function block 30 and the D.sub.TOTAL signal from the computer 24 are applied to the summing junction 55 to provide the D.sub.1 signal representative of the distance of the aircraft from the waypoint A.

Detailed Description Text (99):
The D.sub.TRANS signal from the function block 80 as well as the H.sub.TRANS and H.sub.DECEL signals from the computer 24 are applied to a function block 81 to generate an .alpha..sub.T signal representative of the transition zone flight path angle .alpha..sub.T as illustrated in FIG. 15 in accordance with a function F.sub.5 as follows: ##EQU23##

Detailed Description Text (100):
The D.sub.TRANS signal from the function block 80 as well as the H.sub.TRANS, H.sub.DECEL, D.sub.TOTAL, H.sub.B and H.sub.A signals from the computer 24 are applied to a function block 82 to generate an .alpha..sub.B signal representative of the flight path angle .alpha..sub.B illustrated in FIG. 15 in accordance with a function F.sub.15 as follows: ##EQU24##

Detailed Description Text (102):
The D.sub.1 signal representative of the distance of the aircraft from the waypoint A as provided by the summing junction 55 and the D.sub.A signal from the function block 83 are applied to a compare block 84 wherein conventional comparison circuits provide an output when D.sub.1 is less than D.sub.A. The D.sub.TRANS signal from the function block 80 and the D.sub.A signal from the function block 83 are applied as inputs to a summing junction 85 that provides a signal representative of the sum D.sub.A + D.sub.TRANS. The D.sub.1 output of the summing junction 55 and the D.sub.A + D.sub.TRANS output of the summing junction 85 are applied to a compare block 86 wherein conventional circuits provide an output when D.sub.1 is less than D.sub.A + D.sub.TRANS. It will be appreciated that each of the outputs of the compare circuits 84 and 86 is a binary valued signal in accordance with whether or not the associated comparison is satisifed.

Detailed Description Text (103):
The outputs from the compare circuit 84 and 86 as well as the .alpha..sub.T signal

from the function block 81 and the .alpha..sub.B signal from the function block 82 are applied to a selection matrix 87. The selection matrix 87 comprises conventional circuitry for selecting either the .alpha..sub.T signal from the function block 81 or the .alpha..sub.B signal from the function block 82 and applying the selected signal to the output 46 in accordance with the binary states of the compare circuits 84 and 86. When D.sub.1 is less than D.sub.A or when D.sub.1 is not less than D.sub.A + D.sub.TRANS, the .alpha..sub.B signal is connected to the output 46 of the selection matrix 87. When D.sub.1 is not less than D.sub.A but is less than D.sub.A + D.sub.TRANS, the signal .alpha..sub.T is connected to the output 46 of the selection matrix 87. From the geometry of FIG. 15 it is appreciated that in accordance with the logic described the appropriate flight path angles will be utilized to control the associated legs of the flight path illustrated.

Detailed Description Text (104):
The flight path angle signals .alpha..sub.T and .alpha..sub.B are selected by the selection matrix 87 on the basis of the distance D.sub.1 from the waypoint A. Alternatively, these angles may be selected in accordance with the aircraft altitude with respect to the quantities H.sub.TRANS and H.sub.DECEL from the computer 24. In such an embodiment the air data system 20 provides the signal H.sub.AC representative of the aircraft altitude. In such an alternative embodiment .alpha..sub.B is selected when H.sub.AC is less than H.sub.TRANS or H.sub.AC is greater than H.sub.DECEL. The angle .alpha..sub.T is selected when H.sub.TRANS is less than H.sub.AC and H.sub.AC is less than H.sub.DECEL.

Detailed Description Text (105):
In a manner similar to that described above with regard to FIGS. 9 and 13, the output 46 is connected to the flight path and steering signal computation arrangements 76 for controlling the automatic flight control system 47 for automatically controlling the aircraft flight path in accordance with the selected flight path angle signals .alpha..sub.B and .alpha..sub.T via the pitch control surfaces 50. The output of the steering signal computer 76 is also applied to the flight director 51 which controls the vertical steering pointer 52 of the ADI. The actual deviation of the craft from the path defined by .alpha..sub.B and .alpha..sub.T may also be applied to the glide slope indicator 54 on the HSI or the ADI to provide an indication to the pilot with respect to deviations of the aircraft above or below the selected flight path illustrated in FIG. 15 as defined by the flight path angles .alpha..sub.B and .alpha..sub.T.

Detailed Description Text (106):
Thus it is appreciated that the apparatus of FIG. 16 is utilized to control the aircraft in accordance with the computed flight path illustrated in FIG. 15 as defined by the flight path angles .alpha..sub.B and .alpha..sub.T. The computer 24 provides the air traffic control requirement V.sub.MAX and the air data system 20 provide the speed V.sub.AC utilized in determining the extent of the speed change required to achieve V.sub.MAX. The quantity D.sub.1 (distance of the aircraft from waypoint A) is computed for determining when the deceleration should occur. When the aircraft attains the distance D.sub.A from the waypoint A of FIG. 15 at which point the selection matrix 87 switches from the flight path angle .alpha..sub.B to the flight path angle .alpha..sub.T, the automatic flight control system 47 automatically pitches the aircraft up or the pilot manually executes a pitch up maneuver in response to the command from the pitch command bar 52; deviation monitoring being continuously provided by the glide slope indicator 54. At this point the pilot controls the throttles and utilizes the aircraft airspeed indicator for controlling the speed in the transition zone to effect the required deceleration which for modern jet transports is 2 ft/sec.sup.2. The pilot controls the aircraft speed in this manner while maintaining the pitch command bar on the ADI or the glide slope indicator centered to make good the .alpha..sub.B and .alpha..sub.T flight path angle commands.

Detailed Description Text (107):
It will thus be appreciated that the RNAV system predicts the distance D.sub.TRANS that is required to slow the aircraft from its speed on the first segment of the flight path illustrated in FIG. 15 to the speed V.sub.MAX on the last segment of the illustrated flight path. The system then computes the angle .alpha..sub.B and .alpha..sub.T as discussed above permitting the aircraft to descend without having to deviate from the illustrated prescribed flight path with the vertical deviation on the

HSI remaining centered and the AFCS remaining coupled to the RNAV system. Thus the required speed reduction is attained with the system providing continuous guidance.

Detailed Description Text (108):
Referring now to FIG. 17 in which like reference numeral indicates like components with respect to FIGS. 9, 13 and 16, an alternative embodiment of the invention is illustrated. The air data system 20, the VOR receiver 21, the DME receiver 22, the compass system 23 and the pilot manual data input device 25 provide inputs to a programmed general purpose digital computer 90, the data inputs from the blocks 20, 21, 22, 23 and 25 being similar to those described above with respect to FIGS. 9, 13 and 16. It will be appreciated that conventional analog-to-digital converters (not shown) may be utilized at the input interface of the computer 90 where appropriate. The computer 90 is programmed to provide the pitch steering command signal .theta..sub.c to the AFCS 47 for controlling the pitch control surfaces 50 as well as to the flight director system 51 for providing the pitch command to the pitch command vertical steering bar 52 of the ADI. The digital computer 90 is also programmed to provide flight path deviation signals to the glide slope indicator 54 of the HSI or the ADI as well as signals to the pilot alert device 35, and to the display 37. The computer 90 also effects conventional vertical steering where required as described above. The nature and purpose of the output signals from the computer 90 have been previously described with respect to FIGS. 9, 13 and 16. It will be appreciated that the digital values of these output signals are converted by conventional digital to analog devices (not shown) to provide associated analog signals where appropriate.

Detailed Description Text (111):
Referring now to FIG. 18, the program flow chart for the computations discussed above with respect to FIGS. 4-10 is illustrated. The parameters .alpha..sub.O, .alpha..sub.AC and H.sub.O are computed as illustrated in blocks 91, 92 and 93 of the flow chart of FIG. 18 in a manner similar to that described above with respect to functions F.sub.4, F.sub.5, and F.sub.6 respectively. Decision blocks 94 and 95 determine if the waypoint being approached has an "at-or-above" or an "at-or-below" altitude designation. In accordance with the decision made at the blocks 94 and 95 the program then either algebraically compares the aircraft flight path angle .alpha..sub.AC with the boundary flight path angle .alpha..sub.O in blocks 96 and 97 or provides conventional vertical steering via block 100. If the aircraft is not on an acceptable path in accordance with FIGS. 4-7, the pilot is appropriately alerted in any convenient manner via blocks 101 and 101' after which the program flows to a decision block 102. The decision block 102 determines whether Mach number of indicated airspeed should be utilized in generating the pitch steering command, blocks 103 and 104 providing the command in accordance with airspeed and blocks 105 and 106 providing the command in accordance with Mach number. The pitch command from either the block 104 or 106 selected in accordance with the decision made in the block 102 is applied to the AFCS 47 and to the flight director 51 as described above. The program then enters a block 107 wherein the altitude error signal H.sub.E is generated for application to the glide slope indicator 54 as explained above. After execution of the block 107 the program exits and is thereafter repeatedly reiterated by return to the entry point indicated.

Detailed Description Text (112):
Referring now to FIG. 19, the program flow chart illustrating the computations discussed above with respect to FIGS. 11, 12 and 13 is illustrated. The transition altitude H.sub.TRANS expressed in barometrically corrected terms is converted to pressure altitude H'.sub.TRANS in block 110. The program then flows into decision blocks 111, 112 and 113 wherein decisions are made to determine firstly if the transition altitude is traversed and secondly if the aircraft is ascending or descending through the transition altitude. If the aircraft is ascending through the transition altitude a program path 114 is taken and if the aircraft is descending through the transition altitude a path 115 is followed. If, however, the aircraft does not cross the transition altitude in flying from the waypoint A to the waypoint B (FIGS. 11 and 12), path 116 or 116' is followed by the program flow.

Detailed Description Text (113):
On the program path 114 the parameters .alpha..sub.A, D.sub.A and .alpha..sub.B are computed as indicated in blocks 120, 121 and 122 respectively in a manner similar to that described above with respect to the functions F.sub.7, F.sub.8 and F.sub.9

respectively of FIG. 13. When the program selects the path 115 the parameters .alpha..sub.B, D.sub.A and .alpha..sub.A are computed as illustrated in block 123, 124 and 125 respectively in a manner similar to that described above with respect to the functions F.sub.10, F.sub.11 and F.sub.12 respectively of FIG. 13. The program progresses from the paths 114 and 115 into a decision block 126 wherein the aircraft distance D.sub.1 from the waypoint A (FIGS. 11 and 12) is compared with the parameter D.sub.A to determine which of the flight path angles .alpha..sub.A or .alpha..sub.B should be utilized to provide the vertical steering signal. In accordance with the aircraft location D.sub.1, the program enters either a block 127 or 128 to provide the computed and selected flight path angle .alpha..sub.A or .alpha..sub.B as the flight path reference for the vertical steering signal .theta..sub.c to the automatic flight control system 47 and the flight director 51 as well as for the deviation signals to the glide slope indicator 54 as discussed above. If the path 116 or 116' is selected by the program flow, the normal vertical angle is utilized since these paths bypass the computation paths 114 and 115 for the pressure-barometric altitude transition. Irrespective of which of the paths 114, 115, 116 or 116' is followed by the program, the program flow exits as indicated and subsequently returns to the entry point for repeated iterations of the program.

Detailed Description Text (114):
Referring now to FIG. 20, the program flow chart for the computations discussed above with respect to FIGS. 15 and 16 are illustrated. The parameters D.sub.TRANS, .alpha..sub.T, .alpha..sub.B and D.sub.A are computed as illustrated in blocks 130, 131, 132 and 133 respectively of the flow chart of FIG. 20 in a manner similar to that described above with respect to functions F.sub.13, F.sub.14, F.sub.15 and F.sub.16 respectively. Decision blocks 134 and 135 determine the distance D.sub.1 of the aircraft from the waypoint A of FIG. 15 with respect to the flight path illustrated in the figure. In accordance with the flight path segment on which the aircraft is flying, the vertical angle .alpha..sub.B or .alpha..sub.T is selected as the flight path reference for the vertical steering signal .theta..sub.c for application to the automatic flight control system 47 and the flight director 51 as well as for the deviation signals to the glide slope indicator 54 for controlling the aircraft in accordance therewith as indicated in blocks 136, 137 and 138 respectively. When the aircraft is flying the transition segment in accordance with the block 137 the pilot commands the necessary deceleration to achieve V.sub.MAX at the transition altitude in accordance with block 141. The deceleration may be commanded manually whereby the pilot controls the throttles to appropriately reduce the airspeed. The throttles may also be controlled automatically in systems so equipped. The program exits from the blocks 136, 138 and 141 at the block indicated by the legend and the program flow subsequently returns to the entry point for repeated iterations of the program.

Detailed Description Text (115):
It is thus appreciated from the foregoing that the invention provides vertical navigation in which the aircraft is controlled to meet the demands of the special procedures described above. The "at-or-above" and the "at-or-below" procedures are performed by executing the altitude transition at a constant preselected airspeed. This permits the aircraft to climb or descend at an optimum rate for the power setting selected by the pilot. Control is selectively to Mach number or airspeed. Transitions through the altitude at which the altitude reference baro setting is changed between local baro and 29.92 inches of mercury is performed by the angle computations described above which provide smooth vertical paths without large altitude errors at the transition altitude and eliminate flight path discontinuities. As described above, a deceleration zone is computed so as to compensate the vertical angle on descent paths to permit deceleration to terminal area speeds without the requirement for additional waypoints.

Detailed Description Text (116):
Thus it is appreciated that optimum operational performance is obtained while reducing the pilot work load under the conditions of the vertical navigation tasks discussed above. Smooth and continuous navigation is provided under the above described conditions without the necessity of disconnecting the automatic flight control system from the RNAV system. The above described techniques are consistent with the procedures utilized by the pilot when flying the aircraft manually.

CLAIMS:

1. In an area navigation system for aircraft, apparatus for controlling the vertical flight path of the aircraft when ascending or descending to a waypoint having an altitude and an "at-or-above" or an "at-or-below" altitude requirement associated therewith comprising

vertical steering signal generating means for generating a vertical steering signal representative of deviations of the airspeed of said aircraft from a reference airspeed,

pitch axis control means responsive to said vertical steering signal for controlling the pitch attitude of said aircraft so as to reduce said speed deviations to zero,

boundary parameter computing means for providing a boundary parameter signal representative of the value of a suitable aircraft parameter on a boundary flight path defined by a straight line from the instantaneous location of said aircraft to said waypoint at said altitude thereof,

aircraft parameter computing means of providing an aircraft parameter signal representative of the instantaneous actual value of said aircraft parameter,

means for providing a waypoint data signal representative of said "at-or-above" or said "at-or-below" designation of said waypoint,

comparator means responsive to said boundary parameter signal, said aircraft parameter signal and said waypoint data signal for comparing said aircraft parameter signal to said boundary parameter signal in accordance with said waypoint data signal and providing a pilot alert signal when said actual value of said aircraft parameter relative to said boundary value thereof indicates an actual aircraft flight path tending to violate said "at-or-above" or said "at-or-below" altitude requirement of said waypoint, and

pilot alert means responsive to said pilot alert signal for providing a warning that said aircraft is tending to violate said "at-or-above" or said "at-or-below" altitude requirement.

2. The apparatus of claim 1 in which

said boundary parameter computing means comprises boundary flight path angle computing means for providing a boundary flight path angle signal representative of the value of the flight path angle of said boundary flight path,

said aircraft parameter computing means comprises aircraft flight path angle computing means for providing an aircraft flight path angle signal representative of the instantaneous value of the flight path angle of said aircraft,

said comparator means comprises means responsive to said boundary flight path angle signal, said aircraft flight path angle signal and said waypoint data signal for comparing said aircraft flight path angle signal to said boundary flight path angle signal in accordance with said waypoint data signal and providing said pilot alert signal when said waypoint data signal designates an "at-or-above" waypoint and said aircraft flight path angle is less than said boundary flight path angle or when said waypoint data signal designates an "at-or-below" waypoint and said aircraft flight path angle is greater than said boundary flight path angle.

3. The apparatus of claim 2 further including

means for providing a waypoint altitude signal representative of said altitude of said waypoint,

means for providing an aircraft altitude signal representative of the actual altitude of said aircraft,

means for providing a ground speed signal representative of the ground speed of said aircraft, and

means for providing an altitude rate signal representative of the altitude rate of said aircraft.

4. The apparatus of claim 3 further including distance computing means for providing a distance signal representative of the distance of said aircraft from said waypoint.

5. The apparatus of claim 4 in which said boundary flight path angle computing means comprises means for providing said boundary flight path angle signal in accordance with a function of said waypoint altitude signal, said aircraft altitude signal and said distance signal.

6. The apparatus of claim 5 in which said boundary flight path angle computing means comprises means for computing the function ##EQU26## where .alpha..sub.o = said boundary flight path angle signal

H.sub.w = said waypoint altitude signal

H.sub.AC = said aircraft altitude signal

D = said distance signal.

7. The apparatus of claim 4 in which said aircraft flight path angle computing means comprises means for providing said aircraft flight path angle signal in accordance with a function of said altitude rate signal and said ground speed signal.

8. The apparatus of claim 7 in which said aircraft flight path angle computing means comprises means for computing the function ##EQU27## where .alpha..sub.AC = said aircraft flight path angle signal

H = said altitude rate signal

V.sub.g = said ground speed signal.

9. The apparatus of claim 1 further including

altitude error computing means for generating an altitude error signal representative of the difference between the first firm altitude of a subsequent waypoint in the flight plan of said aircraft and the altitude of said aircraft, and

vertical deviation indicator means responsive to said altitude error signal for providing a visual indication of said difference.

10. The apparatus of claim 1 in which said vertical steering signal generating means comprises

means for providing an actual airspeed signal representative of the actual airspeed of said aircraft,

means for providing an actual mach number signal repesentative of the actual mach number of said aircraft,

means for providing a reference airspeed signal representative of a reference airspeed,

means for providing a reference mach number signal representative of a reference mach number,

means for providing a constant mach number signal representative of a predetermined constant mach number,

a first summing junction responsive to said actual and reference airspeed signals for providing an airspeed difference signal representative of the difference therebetween,

a second summing junction responsive to said actual and reference mach number signals for providing a mach number difference signal representative of the difference therebetween,

comparator means responsive to said actual and constant mach number signals for providing a comparator output signal in accordance with said actual mach number signal exceeding said constant mach number signal, and

selection means responsive to said airspeed difference signal, said mach number difference signal and said comparator output signal for providing said mach number difference signal as said vertical steering signal when said actual mach number signal exceeds said constant mach number signal and for providing said airspeed difference signal as said vertical steering signal when said actual mach number signal does not exceed said constant mach number signal.

11. The apparatus of claim 1 in which said pitch axis control means includes an automatic flight control system responsive to said vertical steering signal for controlling said aircraft about the pitch axis thereof so as to reduce said speed deviation to zero.

13. In the area navigation system of claim 1, apparatus for controlling the vertical flight path of the aircraft when ascending or descending from a first waypoint to a second waypoint through the transition altitude at which the aircraft reference is changed from barometrically corrected altitude to pressure altitude in ascending flight and from pressure altitude to barometrically corrected altitude in descending flight, the altitude of the waypoint above said transition altitude being designated as pressure altitude and the altitude of the waypoint below said transition altitude being designated as barometrically corrected altitude, comprising

first flight path angle computing means for providing a first flight path angle signal representative of a first flight path angle for a first straight line flight path from said first to said second waypoint at said altitudes designated therefor,

second flight path angle computing means for providing a second flight path angle signal representative of a second flight path angle for a second straight line flight path from the point of intersection of said first flight path with said transition altitude to said second waypoint altitude at said altitude designated therefor for ascending flight and to said first waypoint altitude at said altitude designated therefor for descending flight,

selection means responsive to said first and second flight path angle signals for selecting said first flight path angle signal when said aircraft is below said transition altitude and said second flight path angle signal when said aircraft is above said transition altitude,

first further vertical steering signal generating means responsive to said selected flight path angle signal for providing a first further vertical steering signal in accordance with deviations from said straight line flight path defined by said selected flight path angle signal, and

said pitch axis control means being responsive to said first further vertical steering signal for controlling the pitch attitude of said aircraft in accordance therewith.

14. In the area navigation system of claim 13, apparatus for controlling the vertical flight path of the aircraft when descending from a third waypoint to a fourth waypoint through the transition altitude below which the airspeed should be reduced to at most a maximum airspeed, said third and fourth waypoints having respective altitudes associated therewith, comprising

transition distance computing means for providing a transition distance signal representative of a transition distance over which the airspeed is reduced from a first airspeed to said maximum airspeed, the deceleration beginning at a predetermined deceleration altitude,

transition fight path angle computing means responsive to said transition distance

signal for providing a transition flight path angle signal representative of a transition flight path angle for a straight line transition flight path from said deceleration altitude in accordance with said transition distance signal,

descent flight path angle computing means for providing a descent flight path angle signal representative of a descent flight path angle for a first straight line descent flight path segment from said third waypoint at said altitude thereof to the point of intersection of said transition flight path with said deceleration altitude and for a second straight line descent flight path segment from the point of intersection of said transition flight path with said transition altitude to said fourth waypoint at said altitude therefor,

further selection means responsive to said transition and descent flight path angle signals for selecting said descent flight path angle signal when said aircraft is above said deceleration altitude or below said transition altitude and said transition flight path angle signal when said aircraft is between said deceleration and transition altitudes, and

second further vertical steering signal generating means responsive to said selected flight path angle signal for providing a second further vertical steering signal in accordance with deviations from said straight line flight path defined by said selected flight path angle signal,

said pitch axis control means being responsive to said second further vertical steering signal for controlling the pitch attitude of said aircraft in accordance therewith,

the throttles of said aircraft being controlled to effect deceleration on said transition flight path to at most said maximum airspeed.

15. In an area navigation system for aircraft, apparatus for controlling the vertical flight path of the aircraft when ascending from a first waypoint to a second waypoint through the transition altitude at which the aircraft altitude reference is changed from barometrically corrected altitude to pressure altitude, the altitude of said first waypoint being designated as barometrically corrected altitude and the altitude of said second waypoint being designated as pressure altitude, comprising

first flight path angle computing means for providing a first flight path angle signal representative of a first flight path angle for a first straight line flight path from said first to said second waypoint at said altitudes designated therefor,

second flight path angle computing means for providing a second flight path angle signal representative of a second flight path angle for a second straight line flight path from the point of intersection of said first flight path with said transition altitude to said second waypoint at said altitude designated therefor,

selection means responsive to said first and second flight path angle signals for selecting said first flight path angle signal when said aircraft is below said transition altitude and said second flight path angle signal when said aircraft is above said transition altitude,

vertical steering signal generating means responsive to said selected flight path angle signal for providing a vertical steering signal in accordance with deviations from said straight line flight path defined by said selected flight path angle signal, and

pitch axis control means responsive to said vertical steering signal for controlling the pitch attitude of said aircraft in accordance therewith.

16. The apparatus of claim 15 in which said selection means comprises

first distance computing means for providing a first distance signal representative of the lateral distance between said first waypoint and said point of intersection of said first flight path with said transition altitude,

second distance computing means for providing a second distance signal representative of the lateral distance of said aircraft from said first waypoint,

comparator means responsive to said first and second distance signals for providing a comparator signal in accordance with said second distance signal being less than said first distance signal, and

a selection circuit responsive to said first and second flight path angle signal and said comparator signal for providing said first flight path angle signal to said vertical steering signal generating means when said second distance signal is less than said first distance signal and for providing said second flight path angle signal to said vertical steering signal generating means when said second distance signal is not less than said first distance signal.

20. The apparatus of claim 19 in which said first flight path angle computing means comprises means for providing said first flight path angle signal in accordance with a function of said first and second waypoint altitude signals and said total distance signal.

21. The apparatus of claim 20 in which said first flight path angle computing means comprises means for computing the function ##EQU28## where .alpha..sub.A = said first flight path angle signal

H'.sub.a = said first waypoint altitude signal

H'.sub.b = said second waypoint altitude signal

D.sub.total = said total distance signal.

22. The apparatus of claim 19 in which said first distance computing means comprises means for providing said first distance signal in accordance with a function of said transition altitude signal, said first waypoint altitude signal and said first flight path angle signal.

23. The apparatus of claim 22 in which said first distance computing means comprises means for computing the function ##EQU29## where D.sub.A = said first distance signal

H.sub.TRANS = said transition altitude signal

H'.sub.A = said first waypoint altitude signal

.alpha..sub.A = said first flight path angle signal.

24. The apparatus of claim 19 in which said second flight path angle computing means comprises means for providing said second flight path angle signal in accordance with a function of said second waypoint altitude signal, said converted transition altitude signal, said total distance signal and said first distance signal.

25. The apparatus of claim 24 in which said second flight path angle computing means comprises means for computing the function ##EQU30## where .alpha..sub.B = said second flight path angle signal

H.sub.B = said second waypoint altitude signal

H'.sub.TRANS = said converted transition altitude signal

D.sub.TOTAL = said total distance signal

D.sub.A = said first distance signal.

26. The apparatus of claim 15 in which said pitch axis control means includes an automatic flight control system responsive to said vertical steering signal for controlling said aircraft about the pitch axis thereof in accordance therewith.

29. In an area navigation system for aircraft, apparatus for controlling the vertical

flight path of the aircraft when descending from a first waypoint to a second waypoint through the transition altitude at which the aircraft altitude reference is changed from pressure altitude to barometrically corrected altitude, the altitude of said first waypoint being designated as pressure altitude and the altitude of said second waypoint being designated as barometrically corrected altitude, comprising

first flight path angle computing means for providing a first flight path angle signal representative of a first flight path angle for a first straight line flight path from said first to said second waypoint at said altitudes designated therefor,

second flight path angle computing means for providing a second flight path angle signal representative of a second flight path angle for a second straight line flight path from said first waypoint at said altitude designated therefor to the point of intersection of said first flight path with said transition altitude

selection means responsive to said first and second flight path angle signals for selecting said second flight path angle signal when said aircraft is above said transition altitude and said first flight path angle signal when said aircraft is below said transition altitude,

vertical steering signal generating means responsive to said selected flight path angle signal for providing a vertical steering signal in accordance with deviations from said straight line flight path defined by said selected flight path angle signal, and

pitch axis control means responsive to said vertical steering signal for controlling the pitch attitude of said aircraft in accordance therewith.

30. The apparatus of claim 29 in which said selection means comprises

first distance computing means for providing a first distance signal representative of the lateral distance between said first waypoint and said point of intersection of said first flight path with said transition altitude,

second distance computing means for providing a second distance signal representative of the lateral distance of said aircraft from said first waypoint,

comparator means responsive to said first and second distance signals for providing a comparator signal in accordance with said second distance signal being less than said first distance signal, and

a selection circuit responsive to said first and second flight path angle signals and said comparator signal for providing said second flight path angle signal to said vertical steering signal generating means when said second distance signal is less than said first distance signal and for providing said first flight path angle signal to said vertical steering signal generating means when said second distance signal is not less than said first distance signal.

34. The apparatus of claim 33 in which said first flight path angle computing means comprises means for providing said first flight path angle signal in accordance with a function of said first and second waypoint altitude signals and said total distance signal.

35. The apparatus of claim 34 in which said first flight path angle computing means comprises means for computing the function ##EQU31## where .alpha..sub.B = said first flight path angle signal

H'.sub.A = said first waypoint altitude signal

H'.sub.B = said second waypoint altitude signal

D.sub.TOTAL = said total distance signal.

36. The apparatus of claim 33 in which said first distance computing means comprises means for providing said first distance signal in accordance with a function of said

first waypoint altitude signal, said transition altitude signal and said first flight path angle signal.

37. The apparatus of claim 36 in which said first distance computing means comprises means for computing the function ##EQU32## where D.sub.A = said first distance signal

H'.sub.A = said first waypoint altitude signal

H.sub.TRANS = said transition altitude signal

.alpha..sub.B = said first flight path angle signal.

38. The apparatus of claim 33 in which said second flight path angle computing means comprises means for providing said second flight path angle signal in accordance with a function of said converted transition altitude signal, said first waypoint altitude signal and said first distance signal.

39. The apparatus of claim 38 in which said second flight path angle computing means comprises means for computing the function ##EQU33## where .alpha..sub.A = said second flight path angle signal

H'.sub.TRANS = said converted transition altitude signal

H.sub.A = said first waypoint altitude signal

D.sub.A = said first distance signal.

40. The apparatus of claim 29 in which said pitch axis control means includes an automatic flight control system responsive to said vertical steering signal for controlling said aircraft about the pitch axis thereof in accordance therewith.

43. In an area navigation system for aircraft, apparatus for controlling the vertical flight path of the aircraft when ascending or descending from a first waypoint to a second waypoint through the transition altitude at which the aircraft altitude reference is changed from barometrically corrected altitude to pressure altitude in ascending flight and from pressure altitude to barometrically corrected altitude in descending flight, the altitude of the waypoint above said transition altitude being designated as pressure altitude and the altitude of the waypoint below said transition altitude being designated as barometrically corrected altitude, comprising

first flight path angle computing means for providing a first flight path angle signal representative of a first flight path angle for a first straight line flight path from said first to said second waypoint at said altitudes designated therefor,

second flight path angle computing means for providing a second flight path angle signal representative of a second flight path angle for a second straight line flight path from the point of intersection of said first flight path with said transition altitude to said second waypoint altitude at said altitude designated therefor for ascending flight and to said first waypoint altitude at said altitude designated therefor for descending flight,

selection means responsive to said first and second flight path angle signals for selecting said first flight path angle signal when said aircraft is below said transition altitude and said second flight path angle signal when said aircraft is above said transition altitude,

vertical steering signal generating means responsive to said selected flight path angle signal for providing a vertical steering signal in accordance with deviations from said straight line flight path defined by said selected flight path angle signal, and

pitch axis control means responsive to said vertical steering signal for controlling the pitch attitude of said aircraft in accordance therewith.

44. The apparatus of claim 43 in which said selection means comprises

first distance computing means for providing a first distance signal representative of the lateral distance between said first waypoint and said point of intersection of said first flight path with said transition altitude,

second distance computing means for providing a second distance signal representative of the lateral distance of said aircraft from said first waypoint,

comparator means responsive to said first and second distance signals for providing a comparator signal in accordance with said second distance signal being less than said first distance signal, and

a selection circuit responsive to said first and second flight path angle signals and said comparator signal for providing said first flight path angle signal to said vertical steering signal generating means when said second distance signal and for providing said second flight path angle signal to said vertical steering signal generating means when said second distance signal is not less than said first distance signal for ascending flight and for providing said second flight path angle signal to said vertical steering signal generating means when said second distance signal is less than said first distance signal and for providing said first flight path angle signal to said vertical steering signal generating means when said second distance signal is not less than said first distance signal for descending flight.

46. The apparatus of claim 45 including further comparator means responsive to said first and second waypoint altitude signals and said transition altitude signal for providing an ascending flight signal representative of said ascending flight of said aircraft when said second waypoint altitude signal is greater than said transition altitude signal and said first waypoint altitude signal is less than said transition altitude signal and for providing a descending flight signal representative of said descending flight of said aircraft when said second waypoint altitude signal is not greater than said transition altitude signal and said first waypoint altitude signal is greater than said transition altitude signal,

said selection circuit being responsive to said ascending and descending flight signals for providing said first flight path angle signal to said vertical steering signal generating means when said second distance signal is less than said first distance signal and for providing said second flight path angle signal to said vertical steering signal generating means when said second distance signal is not less than said first distance signal in accordance with said ascending flight signal and for providing said second flight path angle signal to said vertical steering signal generating means when said second distance signal is less than said first distance signal and for providing said first flight path angle signal to said vertical steering signal generating means when said second distance signal is not less than said first distance signal in accordance with said descending flight signal.

47. In an area navigation system for aircraft, apparatus for controlling the vertical flight path of the aircraft when descending from a first waypoint to a second waypoint through the transition altitude below which the airspeed should be reduced to at most a maximum airspeed, said first and second waypoints having first and second altitudes associated therewith respectively, comprising

transition distance computing means for providing a transition distance signal representative of a transition distance over which the airspeed is reduced from a first airspeed to said maximum airspeed, the deceleration beginning at a predetermined deceleration altitude,

transition flight path angle computing means responsive to said transition distance signal for providing a transition flight path angle signal representative of a transition flight path angle for a straight line transition flight path from said deceleration altitude to said transition altitude in accordance with said transition distance signal,

descent flight path angle computing means for providing a descent flight path angle signal representative of a descent flight path angle for a first straight line descent flight path segment from said first waypoint at said first waypoint altitude to the

point of intersection of said transition flight path with said deceleration altitude and for a second straight line descent flight path segment from the point of intersection of said transition flight path with said transition altitude to said second waypoint at said second waypoint altitude,

selection means responsive to said transition and descent flight path angle signals for selecting said descent flight path angle signal when said aircraft is above said deceleration altitude or below said transition altitude and said transition flight path angle signal when said aircraft is between said deceleration and transition altitudes.

vertical steering signal generating means responsive to said selected flight path angle signal for providing a vertical steering signal in accordance with deviations from said straight line flight path defined by said selected flight path angle signal, and

pitch axis control means responsive to said vertical steering signal for controlling the pitch attitude of said aircraft in accordance therewith,

the throttles of said aircraft being controlled to effect deceleration on said transition flight path to at most said maximum airspeed.

48. The apparatus of claim 47 in which said selection means comprises

first distance computing means for providing a first distance signal representative of the lateral distance between said first waypoint and said point of intersection of said transition flight path with said deceleration altitude,

second distance computing means for providing a second distance signal representative of the lateral distance of said aircraft from said first waypoint,

summation means responsive to said first distance signal and said transition distance signal for providing a summation signal representative of the algebraic sum thereof,

comparator means responsive to said first and second distance signals and said summation signal for providing comparator signals in accordance with said second distance signal being less than said first distance signal and in accordance with said second distance signal being less than said summation signal, and

a selection circuit responsive to said transition and descent flight path angle signals and said comparator signals for providing said descent flight path angle signal to said vertical steering signal generating means when said second distance signal is less than said first distance signal and when said second distance signal is not less than said summation signal and for providing said transition flight path angle signal to said vertical steering signal generating means when said second distance signal is not less than said first distance signal and is less than said summation signal.

49. The apparatus of claim 48 further including

means for providing a first waypoint altitude signal representative of said altitude of said first waypoint,

means for providing a second waypoint altitude signal representative of said altitude of said second waypoint,

means for providing a total distance signal representative of the lateral distance between said first and second waypoints,

means for providing a deceleration altitude signal representative of said deceleration altitude,

means for providing a transition altitude signal representative of said transition altitude,

means for providing an actual airspeed signal representative of the actual airspeed of said aircraft, and

means for providing a maximum airspeed signal representative of said maximum airspeed.

52. The apparatus of claim 49 in which said transition flight path angle computing means comprises means for providing said transition flight path angle signal in accordance with a function of said deceleration altitude signal, said transition altitude signal and said transition distance signal.

53. The apparatus of claim 52 in which said transition flight path angle computing means comprises means for computing the function ##EQU35## where .alpha..sub.T = said transition flight path angle signal

H.sub.DECEL = said deceleration altitude signal

H.sub.TRANS = said transition altitude signal

D.sub.TRANS = said transition distance signal.

54. The apparatus of claim 49 in which said descent flight path angle computing means comprises means for providing said descent flight path angle signal in accordance with a function of said first waypoint altitude signal, said second waypoint altitude signal, said deceleration altitude signal, said transition altitude signal, said total distance signal and said transition distance signal.

55. The apparatus of claim 54 in which said descent flight path angle computing means comprises means for computing the function ##EQU36## where .alpha..sub.B = said descent flight path angle signal

H.sub.A = said first waypoint altitude signal

H.sub.B = said second waypoint altitude signal

H.sub.DECEL = said deceleration altitude signal

H.sub.TRANS = said transition altitude signal

D.sub.TOTAL = said total distance signal

D.sub.TRANS = said transition distance signal.

56. The apparatus of claim 49 in which said first distance computing means comprises means for providing said first distance signal in accordance with a function of said deceleration altitude signal, said first waypoint altitude signal and said descent flight path angle signal.

57. The apparatus of claim 56 in which said first distance computing means comprises means for computing the function ##EQU37## where D.sub.A = said first distance signal

H.sub.DECEL = said deceleration altitude signal

H.sub.A = said first waypoint altitude signal

.alpha..sub.B = said descent flight path angle signal.

58. The apparatus of claim 47 in which said pitch axis control means includes an automatic flight control system responsive to said vertical steering signal for controlling said aircraft about the pitch axis thereof in accordance therewith.

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L11	L10 and l7	546	L11
L10	compar$3 near l2	4836	L10
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L5	(monitor$3 or sens$3 or detect$3 or identif$4) near l4	77	L5
L4	air traffic	3104	L4
L3	flight	84045	L3
L2	(track$3 or path$3)	1809808	L2
L1	aircraft or aerodyne or airplane	174831	L1

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